VQMT3D Project
Overall Movie Comparison

Report 10

More than 100 movies tested, including:

- Gravity
- The Great Gatsby
- Oz the Great and Powerful
- Stalingrad
- Iron Man 3
- Man of Steel
- Pacific Rim
- Jack the Giant Slayer
- The Hobbit: An Unexpected Journey
- The Legend of Hercules
- Alice in Wonderland
- Pirates of the Caribbean: On Stranger Tides
- The Avengers
- The Amazing Spiderman
- World War Z
- Thor
- The Last Airbender
- Life of Pi
- TRON: Legacy
- Hugo

October 27, 2020

https://videoprocessing.ml/stereo_quality
CS MSU Graphics & Media Lab
http://graphics.cs.msu.ru

Current report contains results that are great news for the following individuals:

- ***3D enthusiasts**. We show that the technical quality of 3D movies has consistently improved over the years, heralding a new surge of interest in 3D.*
- ***3D producers**. Shooting high-quality 3D with up to a 15x lower budget is now possible.*
- ***3D professionals**. New, inexpensive technologies make achieving high technical quality faster and easier.*

105 Blu-ray discs that were analyzed in this report

"I will find it very interesting to go through your report in detail, film by film. ***I had always thought that a major factor holding back the greater success of stereo 3D cinema could be technical problems like those your group has enumerated****."*

John Merritt,
Senior Consulting Scientist
at The Merritt Group,
Founding Chair of the Stereoscopic
Displays & Applications Conference

Foreword

For 11 years our laboratory has researched stereo quality as well as stereo artifacts that cause viewer discomfort. During this time we've created about 20 quality metrics, some of which have undergone considerable improvement. For example, our metric for detecting swapped channels is in its fourth generation, having delivered greater accuracy with each update. At the same time, the computational efficiency of these metrics has exceeded what our competitors have offered, allowing us to analyze real movies.

This work received valuable support from professional stereographers. In total, we corresponded with about 100 stereographers, 32 of whom visibly contributed to our reports. The most notable is Jon Karafin, former VP of Production Technology at RealD. All told, his ideas, suggestions and comments were almost as numerous and beneficial as those from all the others combined. Many stereographers asked us, for example, whether the MSU Scale Mismatch metric value of 4% is high or low for a given movie — an excellent question. Originally, we lacked a clear answer. So we undertook a deliberate effort to directly connect metric values with perceived discomfort, conducting what could be the largest-scale study of real-movie fragments containing artifacts. Also, thanks to the Movie Research Company, we had the unique opportunity to use their impressive test hall—including seats equipped with electroencephalographs (EEGs), eye trackers, high-speed cameras and polygraphs — to collect scads of valuable data. We explored many new aspects of stereoscopic perception, but we also came to recognize how complicated and multidimensional this task is. A primary reason for its complexity is that different people perceive both individual artifacts and combinations thereof in different ways.

We tried to solve this problem from another angle as well. With support from Intel, Cisco and Verizon, we bought more than 150 Blu-ray 3D movies and analyzed them using our metrics. Although this project was complex both technically and organizationally, we obtained a clear picture of how different metrics depend on a movie's release date, budget and production technology.

I thought it important to give a reason why we published this report almost four years after completing our work. We've cooperated with multiple companies and organizations, but their support in recent years has dwindled to zero. Moreover, although several companies whose business depends heavily on the success of 3D movies promised to aid our efforts,these promises went unfulfilled. We're nevertheless happy to finally present you with our 10th Anniversary Report, the first that will be free to download.

We're positive that all current stereoscopic problems will soon be resolved (and we can clearly see how to solve them), yielding a noticeable reduction in viewer discomfort due to stereoscopic movies. And this success will in turn lead to a new surge in stereo's popularity.

Dr. Dmitriy Vatolin Head of Video Group @ CS MSU Graphics & Media Lab

Feedback from Industry Professionals on the VQMT3D Project

Scott Willman (Freelance Stereographer, Stereo Supervisor)
I think your work is very interesting and I truly hope it enlightens as many 3D professionals as possible.

Bill White (CEO at the 3D Camera Company)
Thank you for these studies. I think that they are very comprehensive and good.

Patrick Almanza (Finisher - Comp/Paint at Stereo D)
What an enormous undertaking! This is very useful training information for recognizing and identifying digital imaging artifacts, among other things. I think back to all the films we restored with Lowry Digital, including just about everything great, and if there were such a document detailing everything we had to correct to pristine image restoration, training artists would have been so much easier. You folks deserve kudos!

Jon Karafin (Senior Scientist and Director of Production Technology at RealD)
It is a really great piece of research.

Jon Karafin (Senior Scientist and Director of Production Technology at RealD)
I believe that the strongest section of this document (report #1) is Potential Causes of Visual Discomfort when Viewing Stereo Movies. It is one of the most concise and comprehensive reviews of all of the existing research performed in this field that I have read to date. Well done, and I suggest using this as your opening chapter, as it clearly articulates the underlying thresholds and limits that all stereoscopic metrics have been derived based upon the biology of the visual system.

You are extremely well positioned and have a significant opportunity to truly push the boundaries of this research and be the first to create compelling stereoscopic metrics that accurately define the methodology to clearly articulate quality differentials between differing stereoscopic images.

Paul Taylor (Supervising Sterographer)
I started doing stereoscopic movies twenty five years ago when we shot on film. The 3D business has changed a lot since then and I must say that your project sounds like something we could really use today in our S3D business.

Robert Black (3D R&D and Experimental Psychology, University of Liverpool)
I think the reports are fantastic.

Andrew Parke (Director of Photography, Camera Operator, and Stereographer at DimensionWerks)
Your evaluation was comprehensive and useful in the pursuit of quality Stereoscopic 3D exhibition.

Clyde DeSouza (Stereographer and Creative Technology Evangelist)
If you are an industry professional involved in Stereoscopic 3D films, This is a "MUST HAVE" report.

Tim Baier (Supervising Stereoscopic Technical Director)
The software your team is working on and these reports are a valuable asset to the industry, thank you!

Tim Baier (Supervising Stereoscopic Technical Director)
I'm quite impressed and appreciative of the significant effort that has been invested by MSU to improve the quality of stereoscopic films! Thank you, the industry definitely needs it.

Jordi Alonso (CEO at cine3D.com)
I want to say thank you for those periodical reports, which are brilliant.

Andrew Enyart (Technical Director of Stereography at Sony Pictures Imageworks)
Keep up your hard work. The industry needs people like you.

David Mattingly (Author of The Digital Matte Painting Handbook)
I thought the analysis was fascinating, and very well done. Great, very informative information.

Pawel Achtel (Producer Achtel Pty Limited Stereoscopic 3D Underwater Cinematography)
Thank you for the report. I read them with great interest. It is great reference and educational material. I think you are doing fantastic job for the industry!

Wesley Sewell (Stereographic Supervisor on Marvel's *The Avengers*)
I found all of your diagnoses very interesting. I wish you all the best!

Alaric Hamacher (Professor for 3D Contents at Kwangwoon University)
I am impressed. Since the first reports I saw. You have really gotten a nice amount of data.

> **Jill Smolin (Director of Production Education 3ality Digital LLC)**
> Really extensive work, congratulations. I really wanted to thank you all for the efforts you've put into creating this extensive evaluation of stereoscopic films. Ultimately, this is an awesome report.

> **Zsolt Magyari (Stereographer & Cinematographer, Germany)**
> It is of great importance that you are doing! This can lead to the standardization of stereoscopic quality, that is absolutely necessary for the future of 3D technology.

> **Adriene Hurst (Editor at Digital Media World)**
> Well done to you and your team for doing so much work. Everyone can learn a lot from this report.

> **Brian Gardner (Lead Stereographer on director Ang Lee's *Life Of Pi*)**
> Well done to you and your team for doing so much work. Everyone can learn a lot from this report.

Acknowledgements

We would like to thank all the stereographers and 3D professionals who contributed to the project by providing comments that we included in the first nine reports.:

- **Marcus Alexander**, Stereoscopic Designer, 3D Producer
- **Tim Baier**, Freelance Stereographer & Pipeline TD
- **Ido Banai**, Stereographer, Stereo Production Consultant, Filmmaker, Storyteller
- **Robert Black**, 3D R&D, 3D Consultant / Stereographer
- **Nick Brown**, Stereographer, Stereo Supervisor
- **Olivier Cahen**, Stereoscopic Consultant, Author
- **Ross Copeland**, Online Editor / Stereographer & Colourist, Post-Production Consultant
- **Deepak Dalal**, Associate Stereoscopic Supervisor at Prime Focus World
- **Clyde DeSouza**, Author, Stereographer and Creative Technology Evangelist
- **Lluis Dubreuil**, Stereographer, Stereoscopic Consultant
- **Andrew Enyart**, Stereographer, VFX Supervisor
- **Alfredo Gonzalez**, Stereoscopic Consultant / Stereographer
- **Alaric Hamacher**, Stereographer, Director, Professor at Kwangwoon University
- **Buzz Hays**, 3D producer, director
- **Srboljub Hetlerovic**, Stereographer, VFX supervisor
- **Takashi Kawai**, Professor in the Department of Intermedia Art and Science at Waseda University
- **Markus Lanxinger**, Stereographer, Stereoscopic Supervisor
- **Ed W. Marsh**, Filmmaker
- **John Merritt**, Senior Consulting Scientist at The Merritt Group
- **Julian Napierr**, Director, Editor, Stereographer
- **Greg Passmore**, Director, PassmoreLab
- **Enrico Perei**, On-Set/Post Production Stereographer, VFX Supervisor
- **Daniele Pugni**, 3D-Motion Graphic Designer Freelancer for Sky 3D Channel
- **Fabien Remblier**, S3D and 4K Director, Stereographer, Producer
- **Wesley Sewell**, Stereographic Supervisor
- **Jill Smolin**, Director of Production Education for 3ality Technica
- **Paul Taylor**, Supervising Stereographer
- **Celine Tricart**, Independent Filmmaker and Stereographer
- **Pan Vafeiadis**, Senior Lecturer in Visual Effects, Nuke Trainer, Senior Stereoscopic Compositor
- **Thomas Villepoux**, Director, Stereographer

Special thanks go to Jon Karafin, who offered numerous remarks and suggestions while working as a Senior Scientist and Director of Production Technology at RealD. His feedback and ideas were invaluable early in the project's development.

Our 2019 project "Development of a system for automatic objective quality assessment and correction of stereoscopic video and video in VR180 format" received support under the START program of the State Fund for Support of Small Enterprises in the Scientific-Technical Fields.

Contents

Disclaimer

1. Metric values make possible to claim that one movie is better on average than another movie according to this particular metric only. Comparing two movies with average metric values, one cannot be sure that a movie with better metric value is indeed better for a viewer. We are striving to measure viewer's perception, but there is still a lot of work to be done. The presented metrics have limitations, and they are to be improved. The metrics may be improved by VQMT3D team as well as by any researcher or research team. Despite the existing shortcomings the metrics definitely enable quality assessment of S3D video and may be beneficial.

2. The object of this evaluation is a set of movie copies which were bought at *Amazon* store as Blu-ray discs. It is possible that detected problems exist only in a particular Blu-ray release and did not affect viewers in a cinema theatre. However, the nature of many problems makes it problematic to believe that they might be introduced in any presumptive post-production stage done exclusively for a Blu-ray release.

3. Readers should note that the comparison of converted and captured S3D movies presented in this report is generally unfair, as it doesn't take into account problems specific to converted movies. But it clearly shows how 2D-3D conversion approach helps eliminate some of the artifacts that commonly appear in captured S3D movies. 2D-3D conversion introduces, however, specific artifacts that are beyond the scope of this report. Some of these artifacts were analyzed in the previous reports [3, 5].

4. The movie ratings presented in this report compare movies only in terms of technical quality measured with our set of metrics. Higher ranking of a movie in some category doesn't necessarily mean that this movie is indeed better for a viewer.

5. All necessary movie information (release date and budget) is taken from the IMDb website (`http://www.imdb.com`). Note that provided movie budget may be somewhat deceptive, as we do not know how much of the budget was spent on S3D postproduction (capturing or conversion).

6. The movie type classification was made based on information from public sources. Thus, it may contain some inaccuracies. Also, the majority of evaluated movies contain elements of CGI. Therefore, we avoid distinguishing capturing+CGI and conversion+CGI as separate movie types.

Chapter 1

Introduction

This document is the tenth report from the Video Quality Measurement Tool for 3D (VQMT3D) project. It's unusual in that it provides a more thorough and detailed overall comparison of stereo-3D (S3D) movies and omits all individual-movie evaluation results (artifact visualizations, per-frame analysis charts and so on). The CS MSU Graphics & Media Lab (Moscow, Russia) team leads the project.

1.1 Movie Selection

This report addresses all types of S3D movies (natively captured, post-converted, hybrid and fully rendered in 3D). We tried to cover as many Blu-ray 3D movies as possible (our evaluation took place in the spring of 2014), with a main criterion for our selection being based on budget data from the IMDb website. We found and evaluated 98 such movies, as well as 7 movies that lacked a specified budget. The present work evaluates the Blu-ray releases of these films. Therefore, the comparison is fair, as each one we analyzed is intended for viewing on home stereoscopic-cinema systems.

1.2 Document Organization

The report comprises four main parts. The second section presents an overall comparison of the movies we evaluated. It includes charts depicting the average metric values relative to a movie's release date and budget, as well as charts illustrating metric-value distributions.

In the third section we rate movies on the basis of our metrics for multiple categories. Different metrics correspond to different categories, as do low- versus high-budget movies and movies with distinct release years. We also present an overall technical-quality comparison that combines all the relevant results for the various quality metrics.

The fourth section sums up the ratings in the previous section by concisely listing movies by their total number of nominations. The final part describes our plans for continuing this project.

Chapter 2

Overall Comparison Charts

2.1 Depth Budget

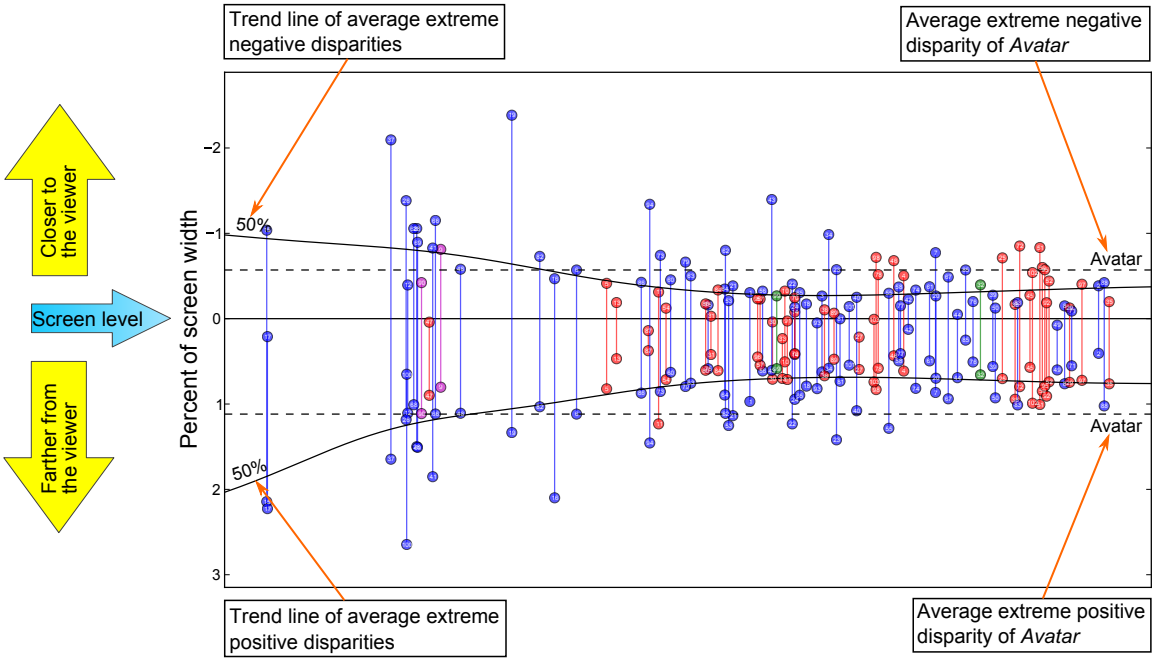


Figure 2.1: Example of a depth budget chart where average extreme negative and positive disparities are depicted

We use four types of diagrams to illustrate and compare the depth budgets of S3D films. The first depicts average extreme negative and positive disparities for each movie relative to its release date (Figure 2.1). Each movie therefore has two corresponding points; a line connecting these points represents the movie's average depth budget. The second diagram is a bar chart that sorts movies by average depth budget in ascending order. Also, we provide two stacked bar charts to clarify the depth-budget-value distributions for different films. The first one sorts movies by the number of small-depth-budget scenes and the second sorts them by the number of large-depth-budget scenes. And, finally, we provide a chart depicting average disparity distributions, highlighting each film's most commonly occurring disparity values. We measure horizontal disparity values in percent of frame width (0.5% equals $\sim$ 10 pixels in Full HD). A more thorough description of this metric appears in [10].

See Excessive Horizontal Disparity Examples in Our Previous Reports (1578 pages and 1879 figures in total, 3 years of preparation and publication)

A lot of excessive horizontal disparity examples in captured and converted movies (385 figures in total) and per-frame analysis charts can be found here:

- MSU VQMT3D Report 1 "5 Natively Captured Movies" (March 2013, 246 pages, 295 figures) [1]
- MSU VQMT3D Report 2 "5 Natively Captured Movies" (May 2013, 342 pages, 442 figures) [2]
- MSU VQMT3D Report 3 "5 Converted Movies" (August 2013, 305 pages, 336 figures) [3]
- MSU VQMT3D Report 4 "5 Natively Captured Movies" (October 2013, 301 pages, 402 figures) [4]
- MSU VQMT3D Report 5 "5 Converted Movies" (April 2014, 384 pages, 404 figures) [5]

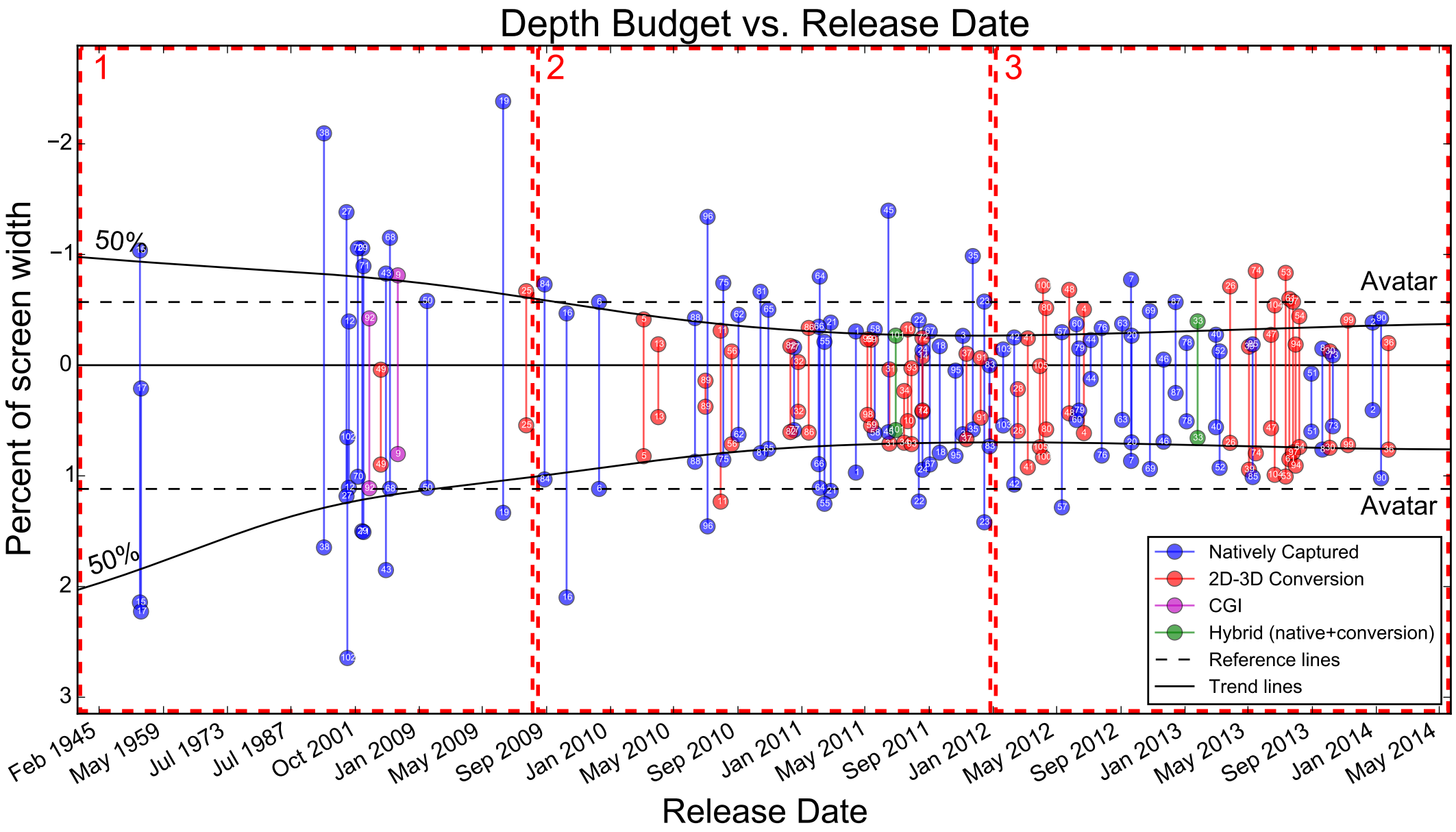


Figure 2.2: Diagram illustrating average depth budget of movies relative to release date. Magnified fragments of the diagram are presented in the following Figures: 2.2a, 2.2b, 2.2c

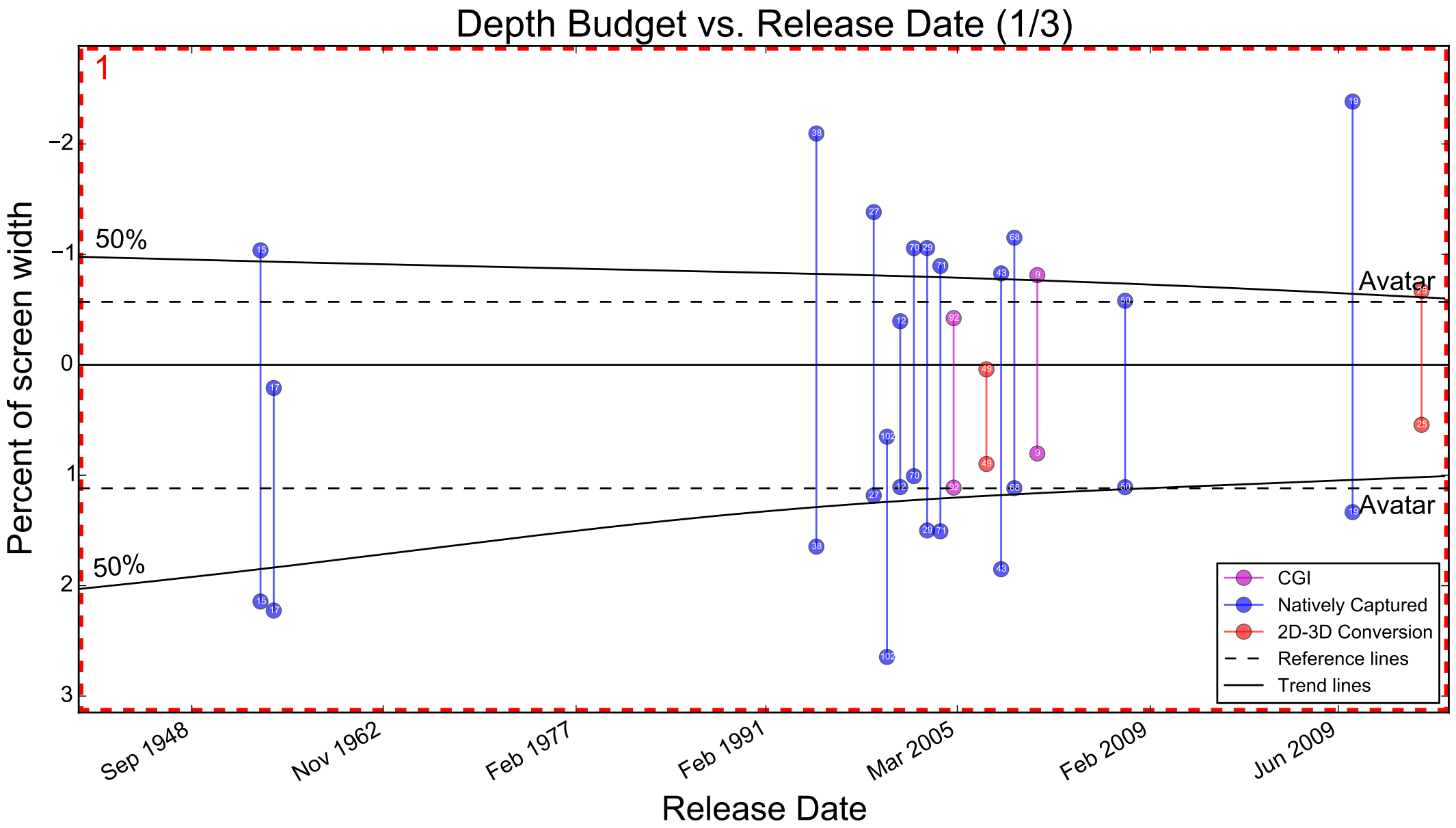


Figure 2.2a: First magnified fragment of the diagram in Figure 2.2

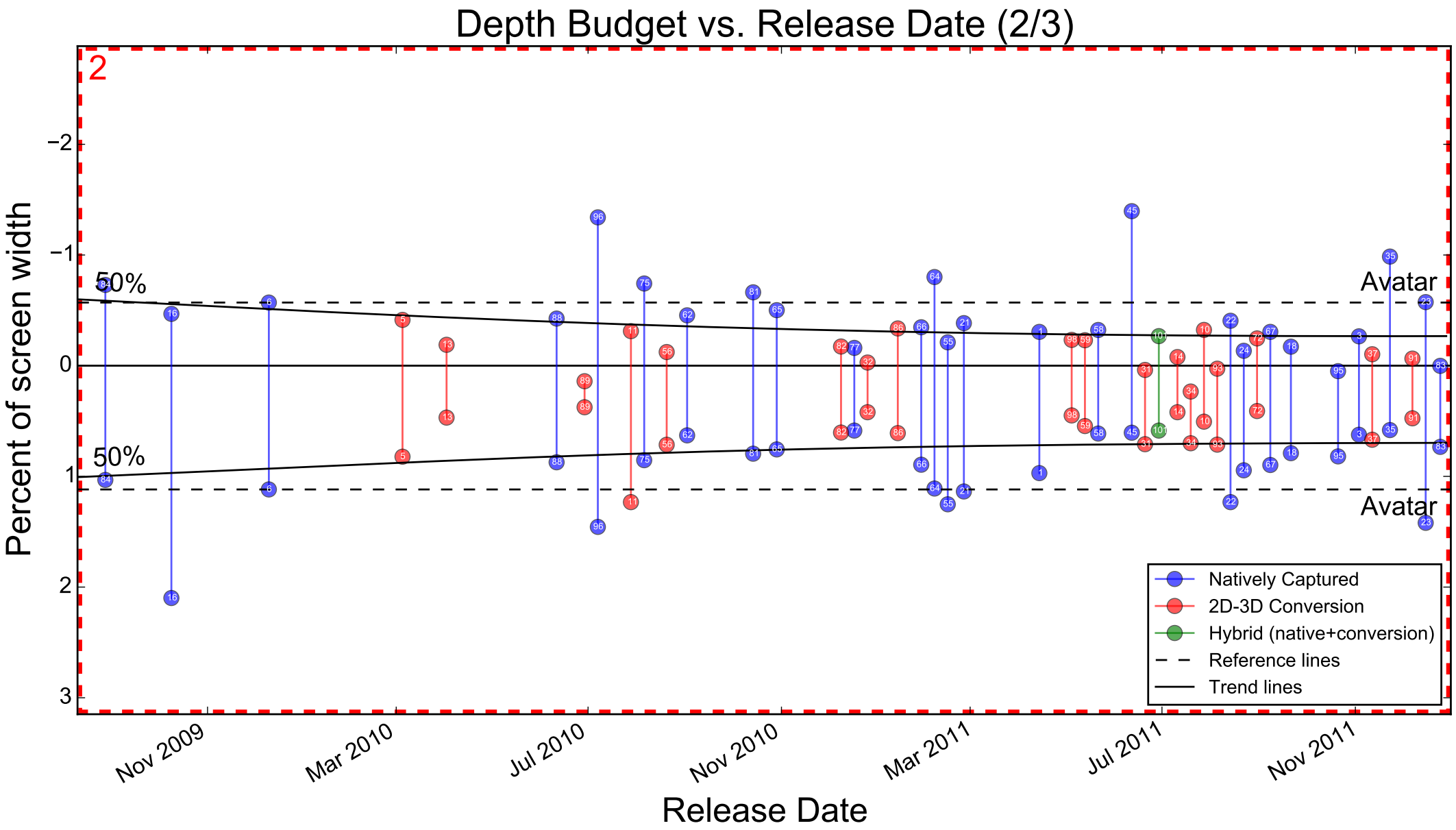


Figure 2.2b: Second magnified fragment of the diagram in Figure 2.2

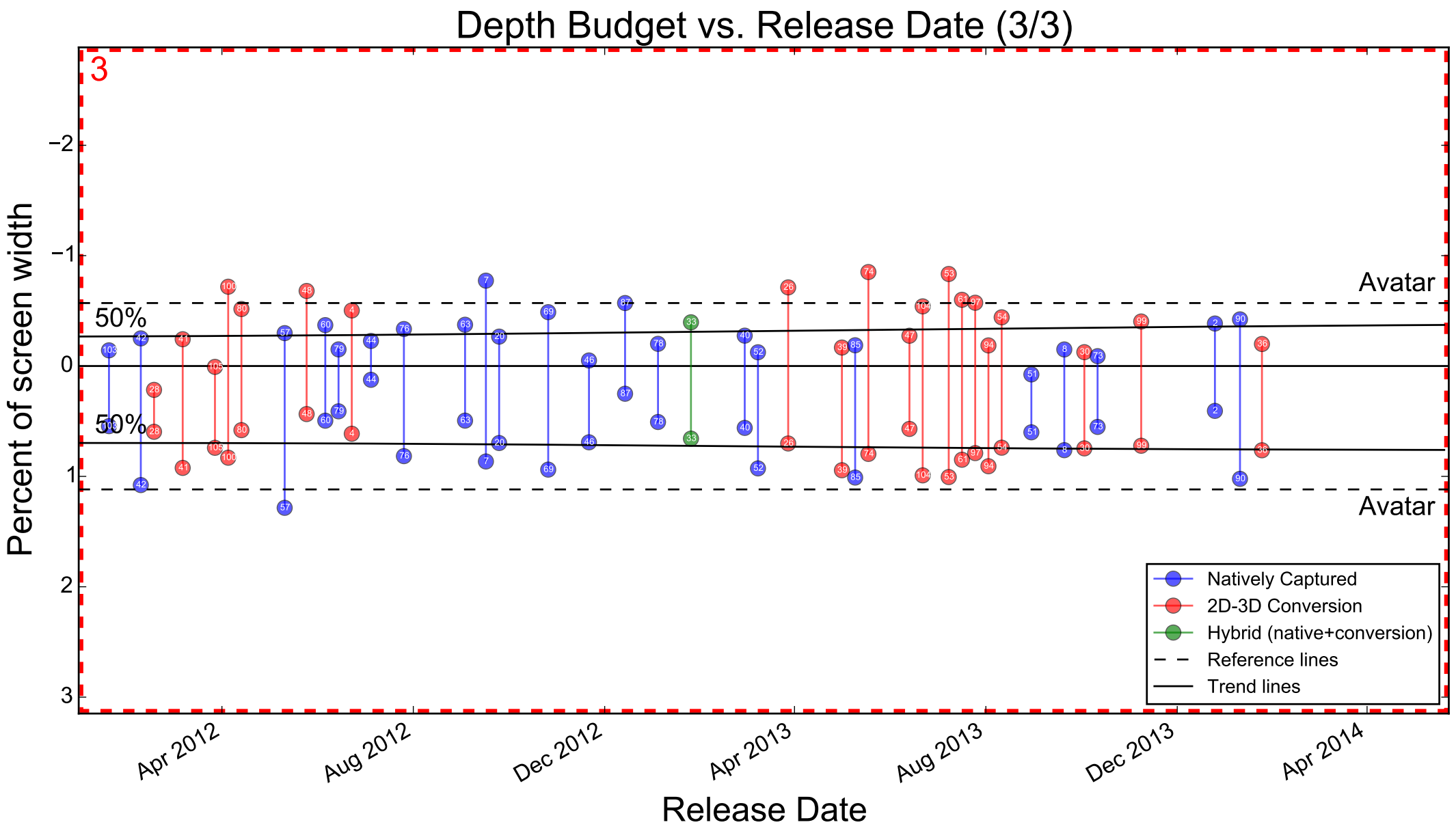


Figure 2.2c: Third magnified fragment of the diagram in Figure 2.2

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

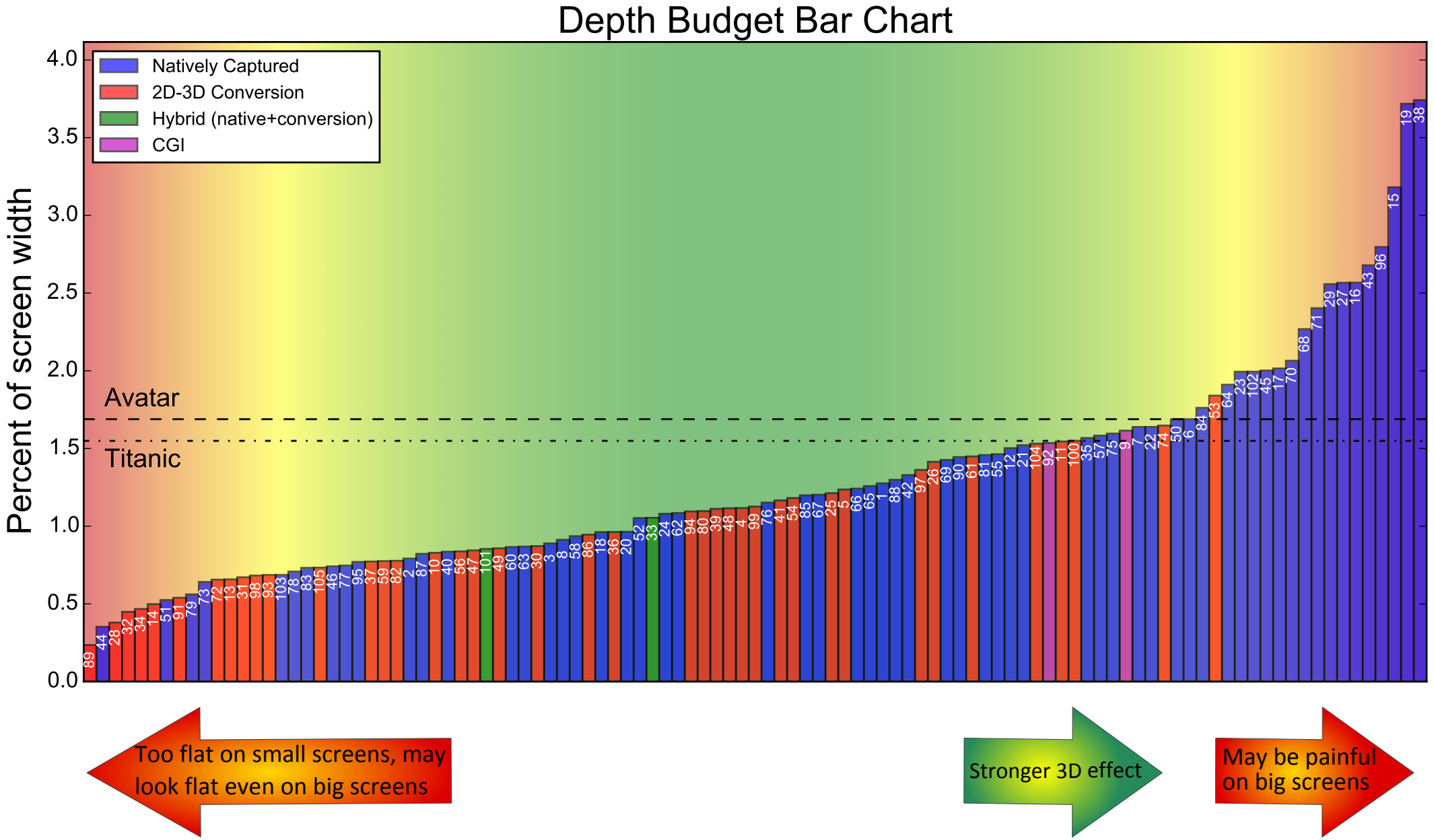


Figure 2.3: Bar chart with movies sorted by average depth budget in ascending order

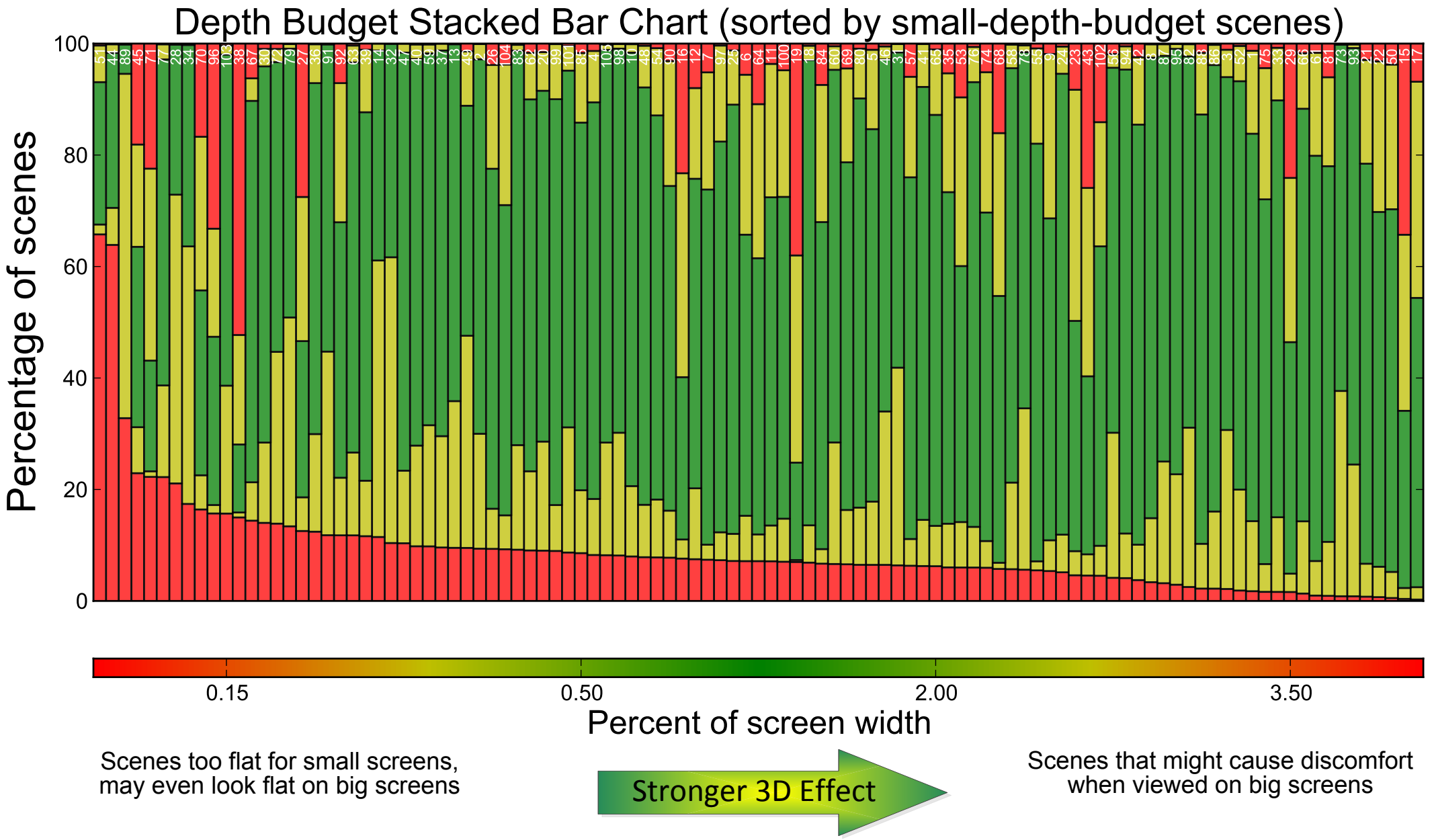


Figure 2.4: Stacked bar chart with movies sorted by the amount of scenes with small depth budget

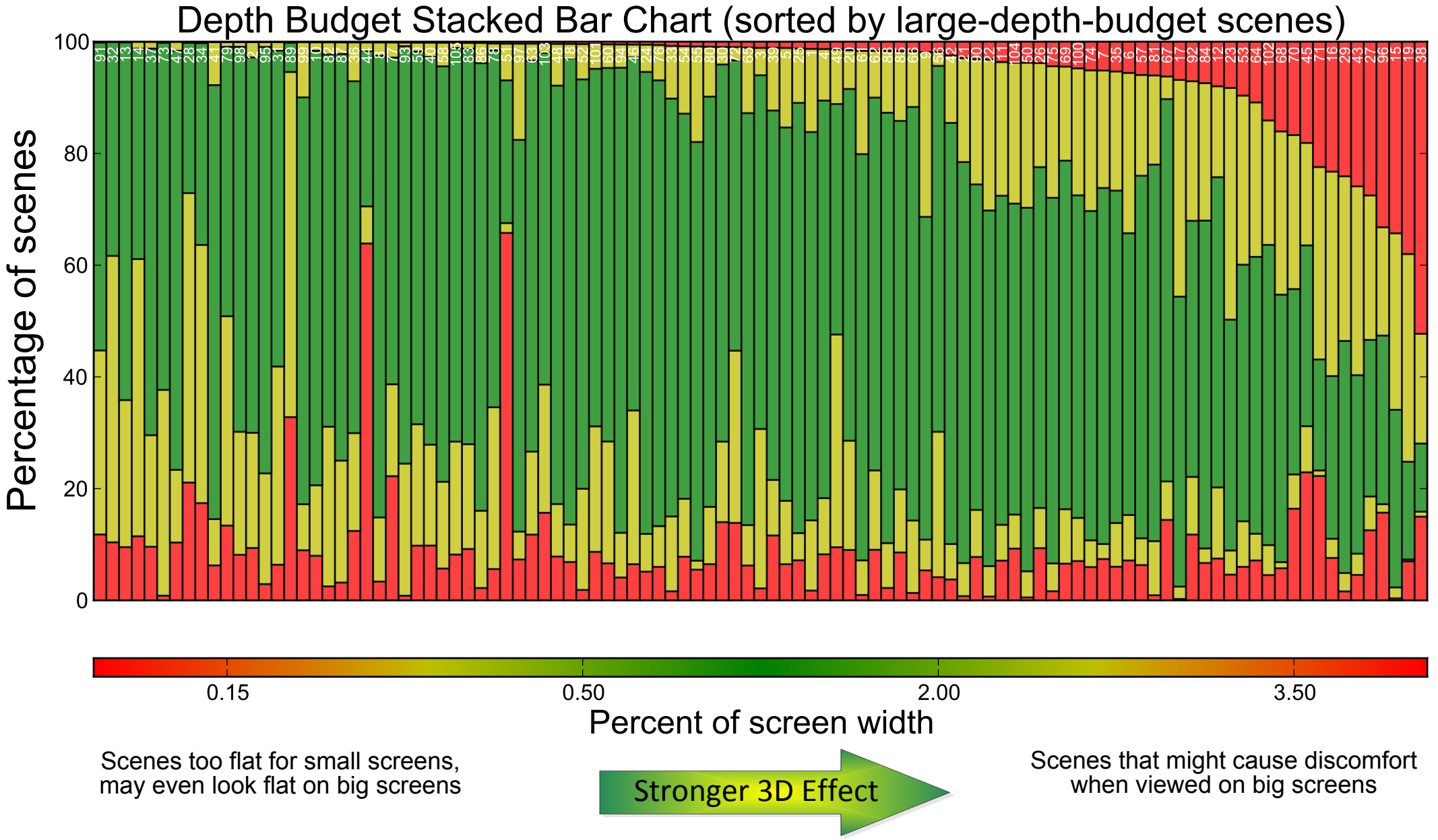


Figure 2.4a: Stacked bar chart with movies sorted by the amount of scenes with large depth budget

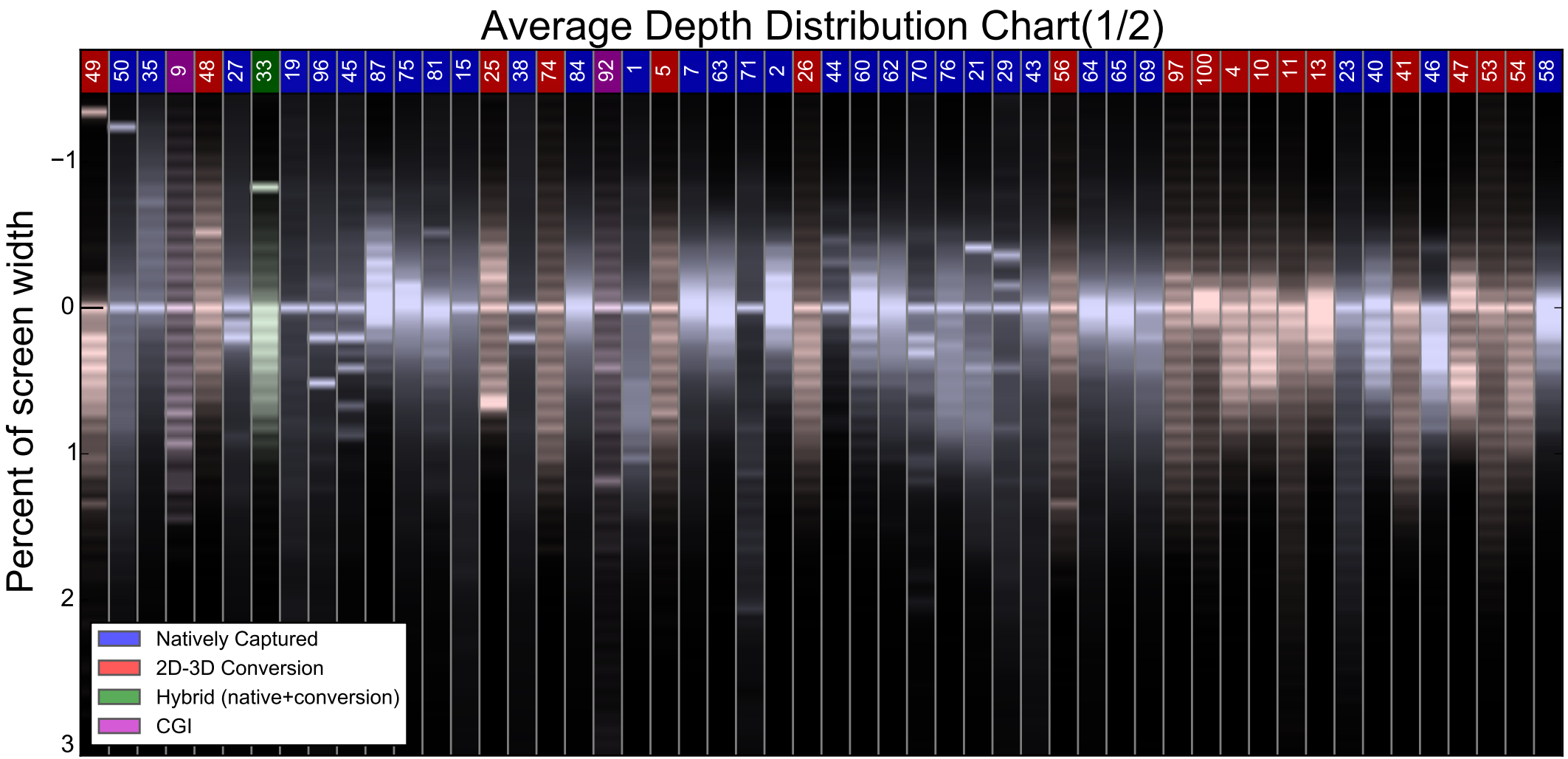


Figure 2.5: First part of a diagram illustrating average disparity distributions of different movies. Most commonly occurring disparity values (throughout a whole movie) are highlighted with white color

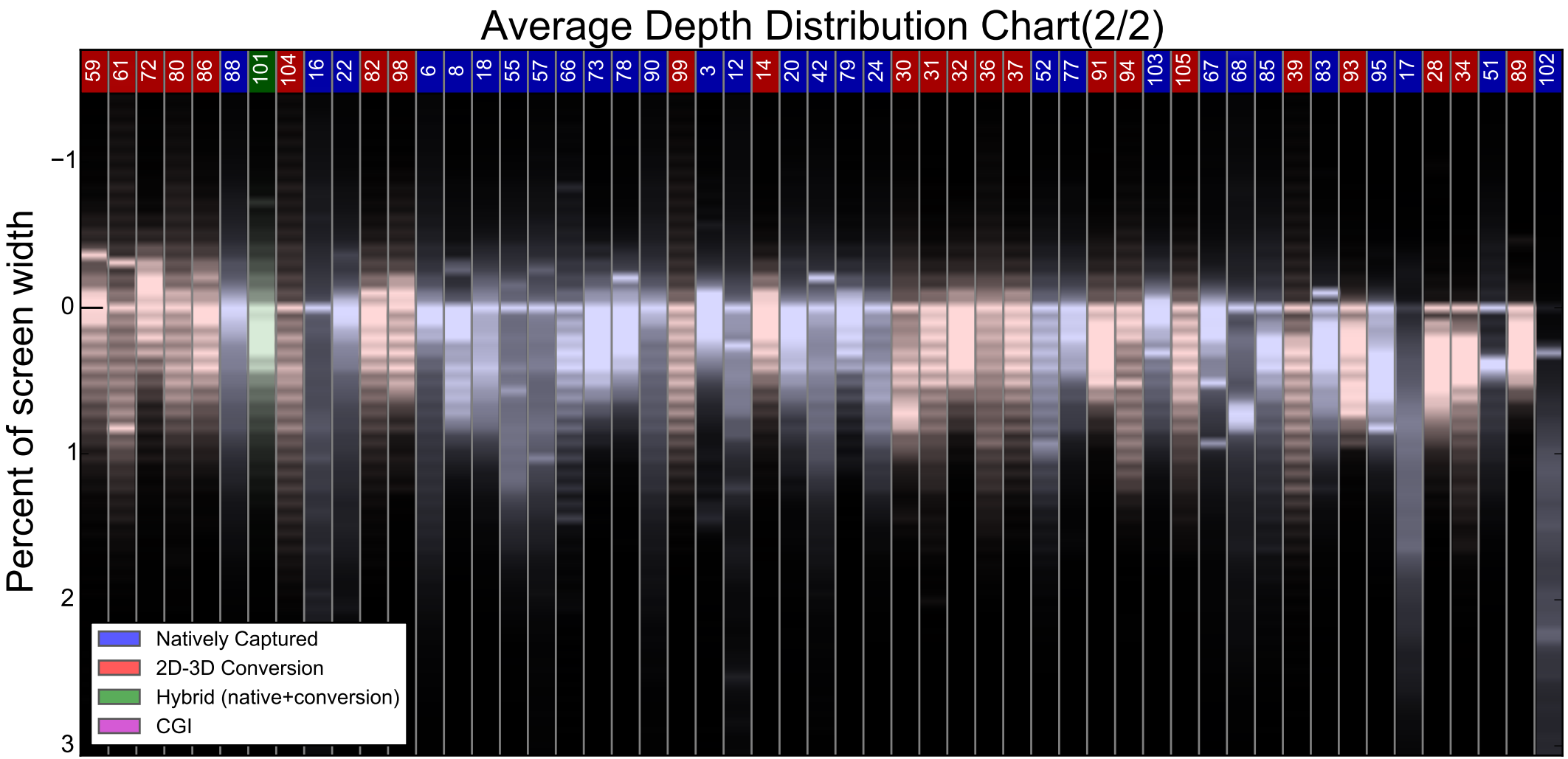


Figure 2.5a: Second part of a diagram illustrating average disparity distributions of different movies. Most commonly occurring disparity values(throughout a whole movie) are highlighted with white color

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy
2: 47 Ronin
3: A Very Harold & Kumar 3D Christmas
6: Avatar
7: Bait
8: Battle of the Year
12: Cirque du Soleil: Journey of Man
15: Creature from the Black Lagoon
16: Dark Country
17: Dial M for Murder
18: Dolphin Tale
19: Dolphins and Whales 3D: Tribes of the Ocean
20: Dredd
21: Drive Angry
22: Final Destination 5
23: Flying Swords of Dragon Gate
24: Fright Night
27: Galapagos: The Enchanted Voyage
29: Ghosts of the Abyss
35: Hugo
38: Into the Deep
40: Jack the Giant Slayer
42: Journey 2: The Mysterious Island
43: Journey to the Center of the Earth
44: Katy Perry: Part of Me
45: Legends of Flight
46: Life of Pi
50: My Bloody Valentine
51: One Direction: This Is Us
52: Oz the Great and Powerful
55: Pina
57: Piranha 3DD
58: Pirates of the Caribbean: On Stranger Tides
60: Prometheus
62: Resident Evil: Afterlife
63: Resident Evil: Retribution
64: Sanctum
65: Saw 3D: The Final Chapter
66: Sea Rex 3D: Journey to a Prehistoric World
67: Shark Night 3D
68: Sharks 3D
69: Silent Hill: Revelation 3D
70: Space Station 3D
71: Spy Kids 3-D: Game Over
73: Stalingrad
75: Step Up 3D
76: Step Up Revolution
77: TRON: Legacy
78: Texas Chainsaw 3D
79: The Amazing Spiderman
81: The Child's Eye
83: The Darkest Hour
84: The Final Destination
85: The Great Gatsby
87: The Hobbit: An Unexpected Journey
88: The Hole
90: The Legend of Hercules
95: The Three Musketeers
96: The Ultimate Wave Tahiti
102: Ultimate G's
103: Underworld: Awakening

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters
101: Transformers: Dark of the Moon

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter
5: Alice in Wonderland
10: Captain America: The First Avenger
11: Cats & Dogs: The Revenge of Kitty Galore
13: Clash of the Titans
14: Conan the Barbarian
25: G-Force
26: G.I. Joe: Retaliation
28: Ghost Rider: Spirit of Vengeance
30: Gravity
31: Green Lantern
32: Gulliver's Travels
34: Harry Potter and the Deathly Hallows: Part 2
36: I, Frankenstein
37: Immortals
39: Iron Man 3
41: John Carter
47: Man of Steel
48: Men in Black 3
49: Mummies: Secrets of the Pharaohs
53: Pacific Rim
54: Percy Jackson: Sea of Monsters
56: Piranha 3D
59: Priest
61: R.I.P.D.
72: Spy Kids: All the Time in the World in 4D
74: Star Trek Into Darkness
80: The Avengers
82: The Chronicles of Narnia: The Voyage of the Dawn Treader
86: The Green Hornet
89: The Last Airbender
91: The Nutcracker in 3D
93: The Smurfs
94: The Smurfs 2
97: The Wolverine
98: Thor
99: Thor: The Dark World
100: Titanic
104: World War Z
105: Wrath of the Titans

CGI

9: Bolt
92: The Polar Express

2.2 Depth Continuity

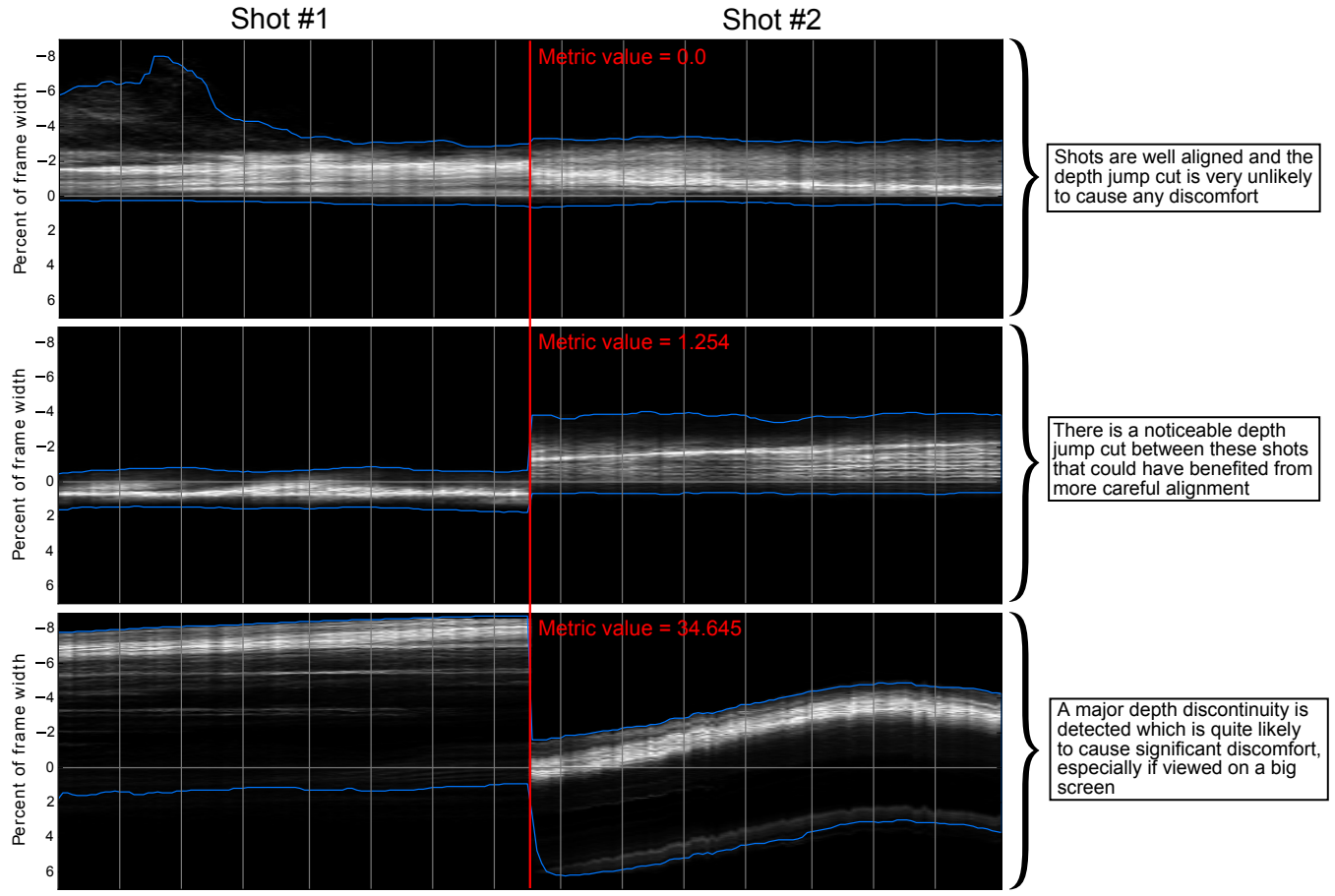


Figure 2.6: Illustration of the depth continuity metric on several examples. Brighter areas on the chart correspond to more common disparity values in a shot

In this section we compare movies by depth continuity. A widely known fact is that avoiding major depth-jump cuts (sudden depth changes in a frame's salient regions) is crucial to a pleasant viewing experience. We developed a metric that estimates these depth jumps, assuming a simple visual-saliency model based on two cues: center prior and defocus. The metric's final value is dimensionless; higher values indicate more-frequent and more-intense depth-jump cuts throughout a film.

We provide three straightforward diagrams to examine the depth continuity of different movies. The first two illustrate metric values relative to release date and budget. The last one is a simple bar chart that ranks movies by depth continuity.

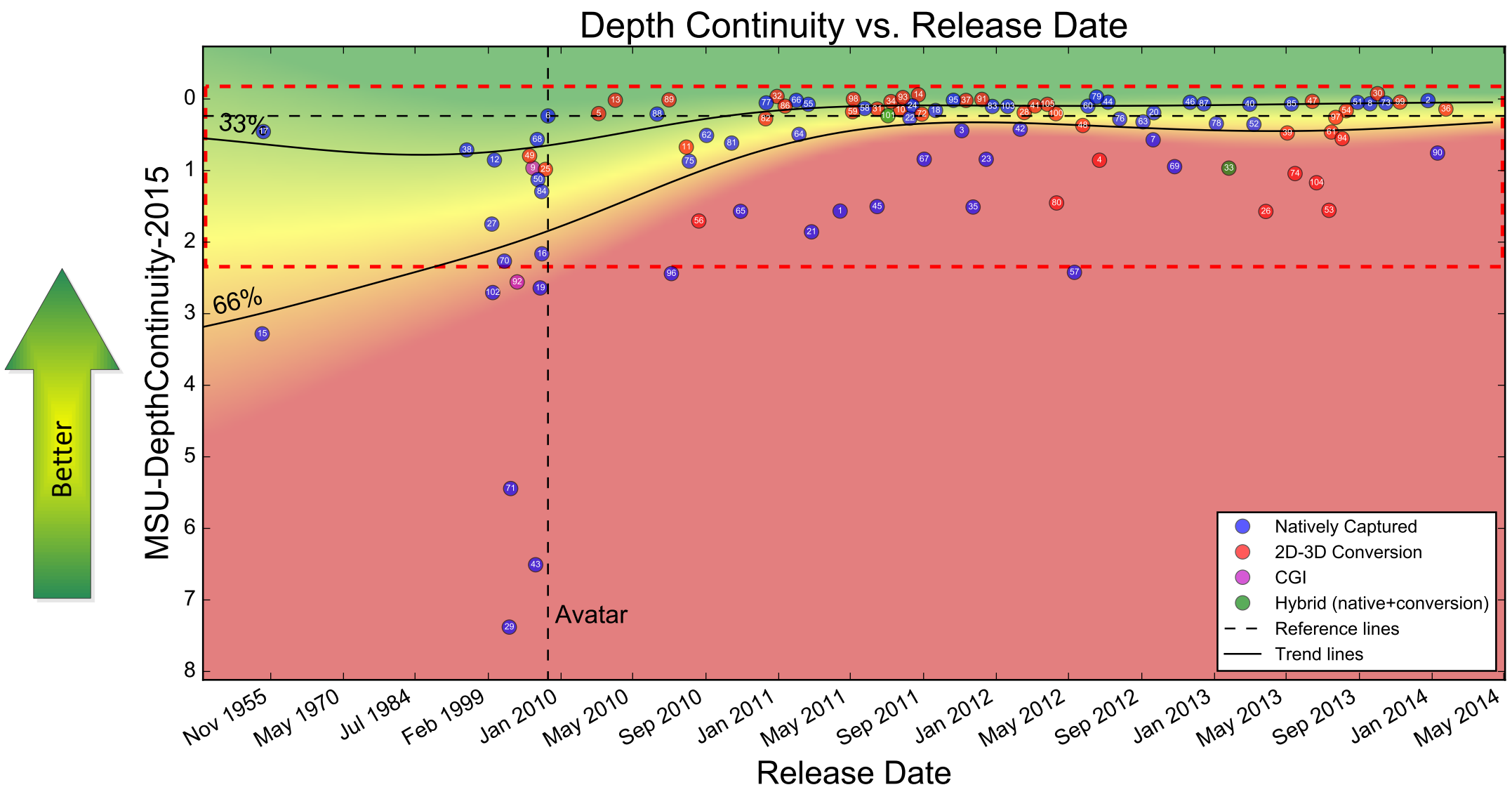


Figure 2.7: Diagram illustrating depth continuity metric value relative to movie release date

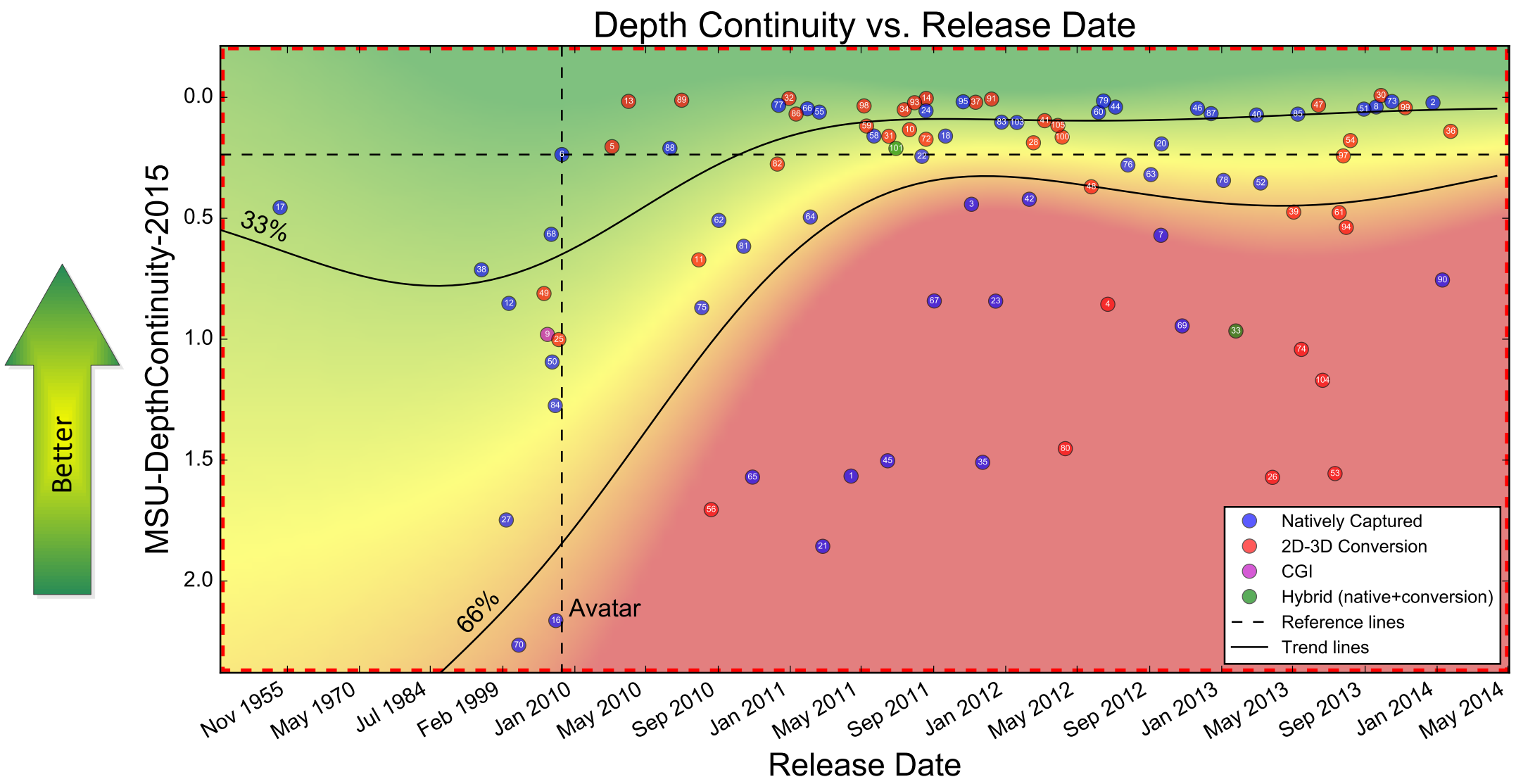


Figure 2.7a: Magnified fragment of the diagram in Figure 2.7

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

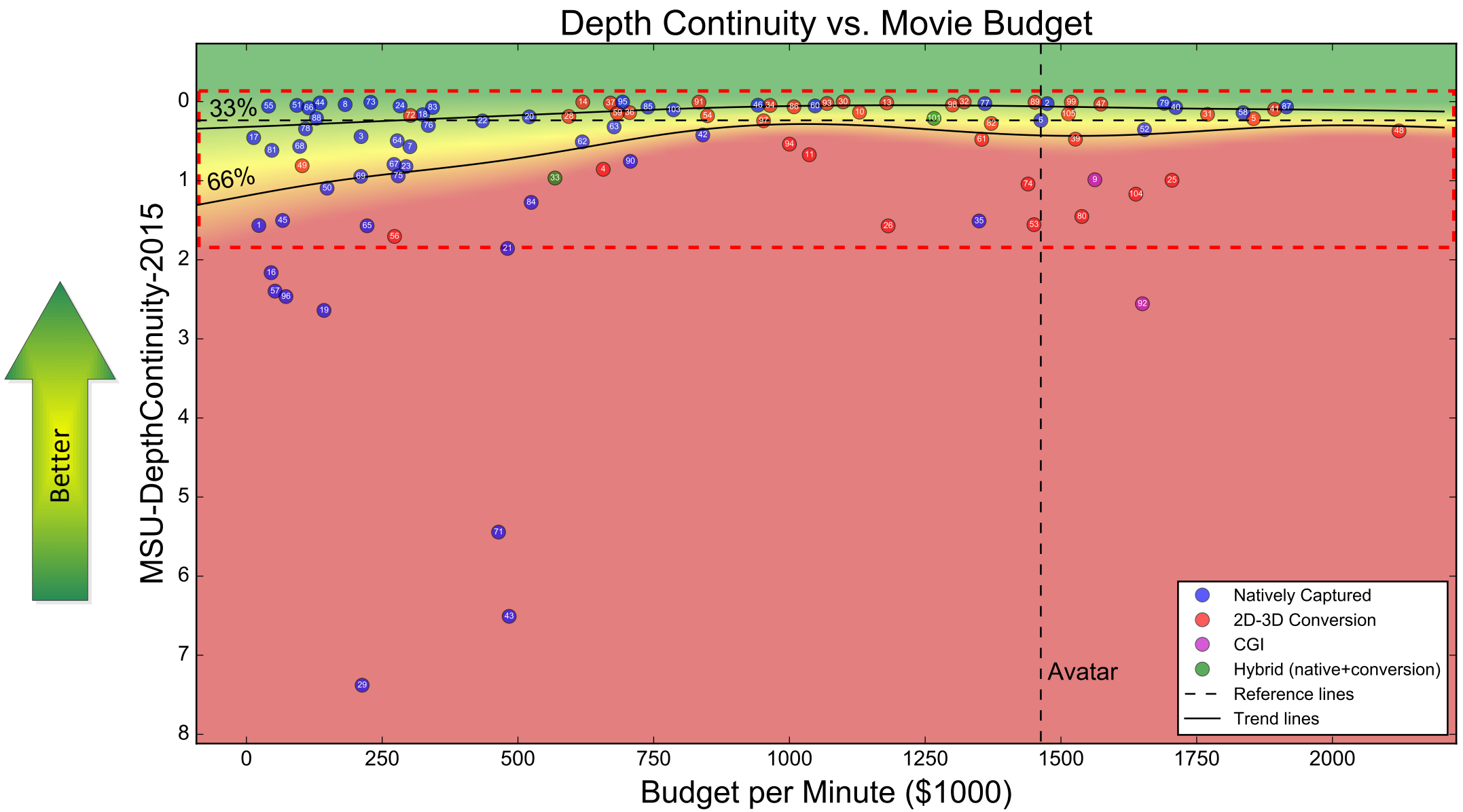


Figure 2.8: Diagram illustrating depth continuity metric value relative to movie budget (per minute)

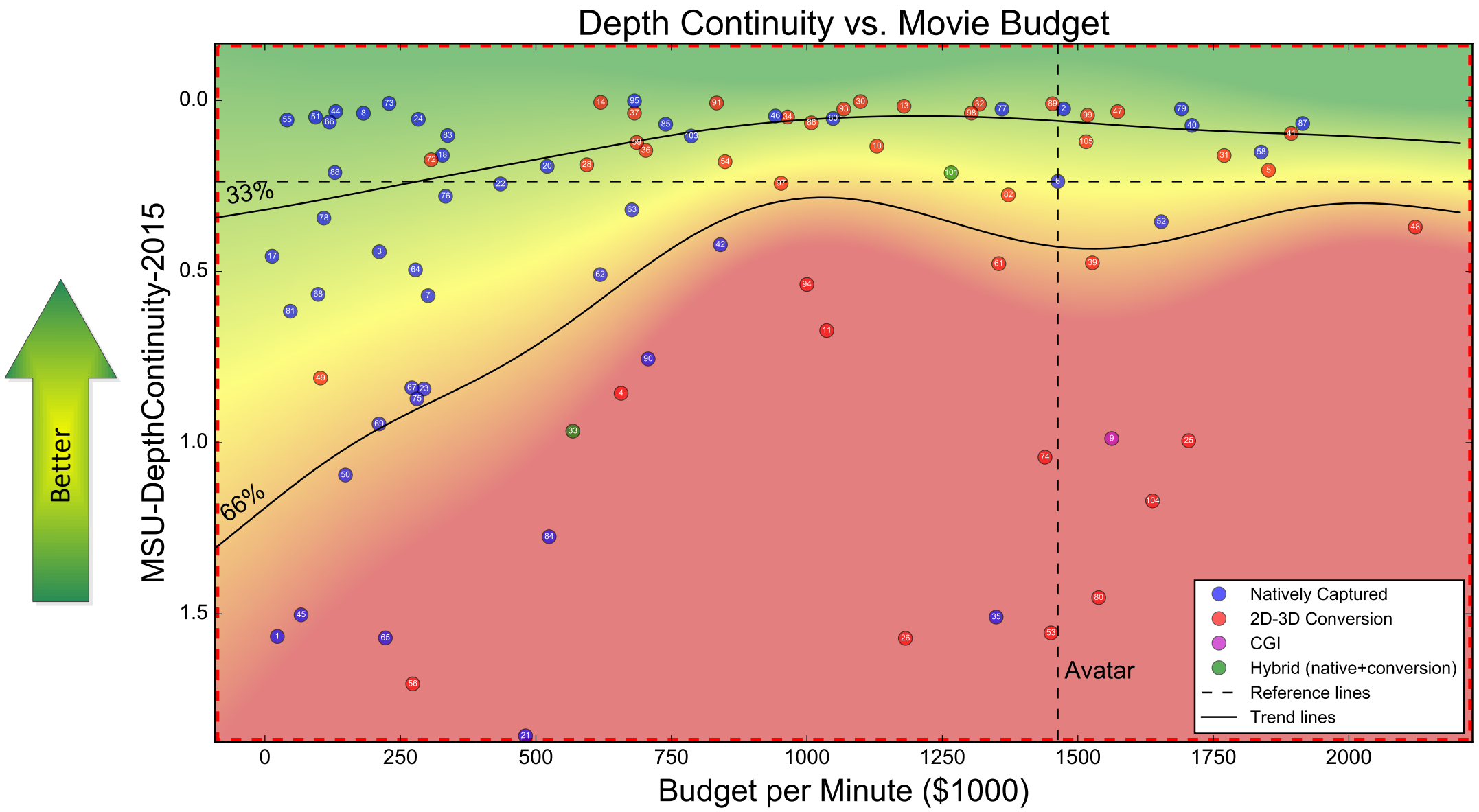


Figure 2.8a: Magnified fragment of the diagram in Figure 2.8

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

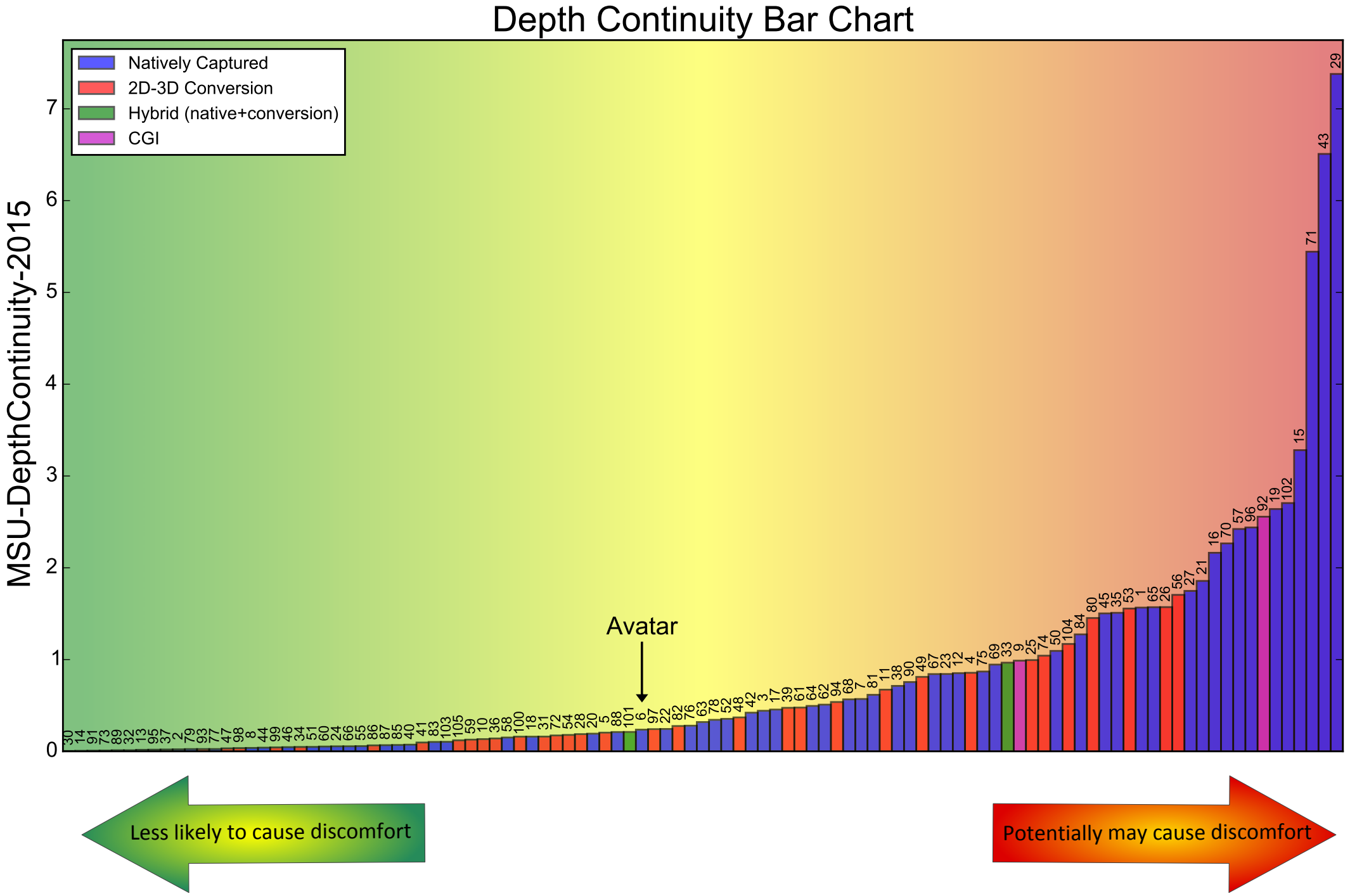


Figure 2.9: Bar chart with movies sorted by depth continuity metric value in ascending order

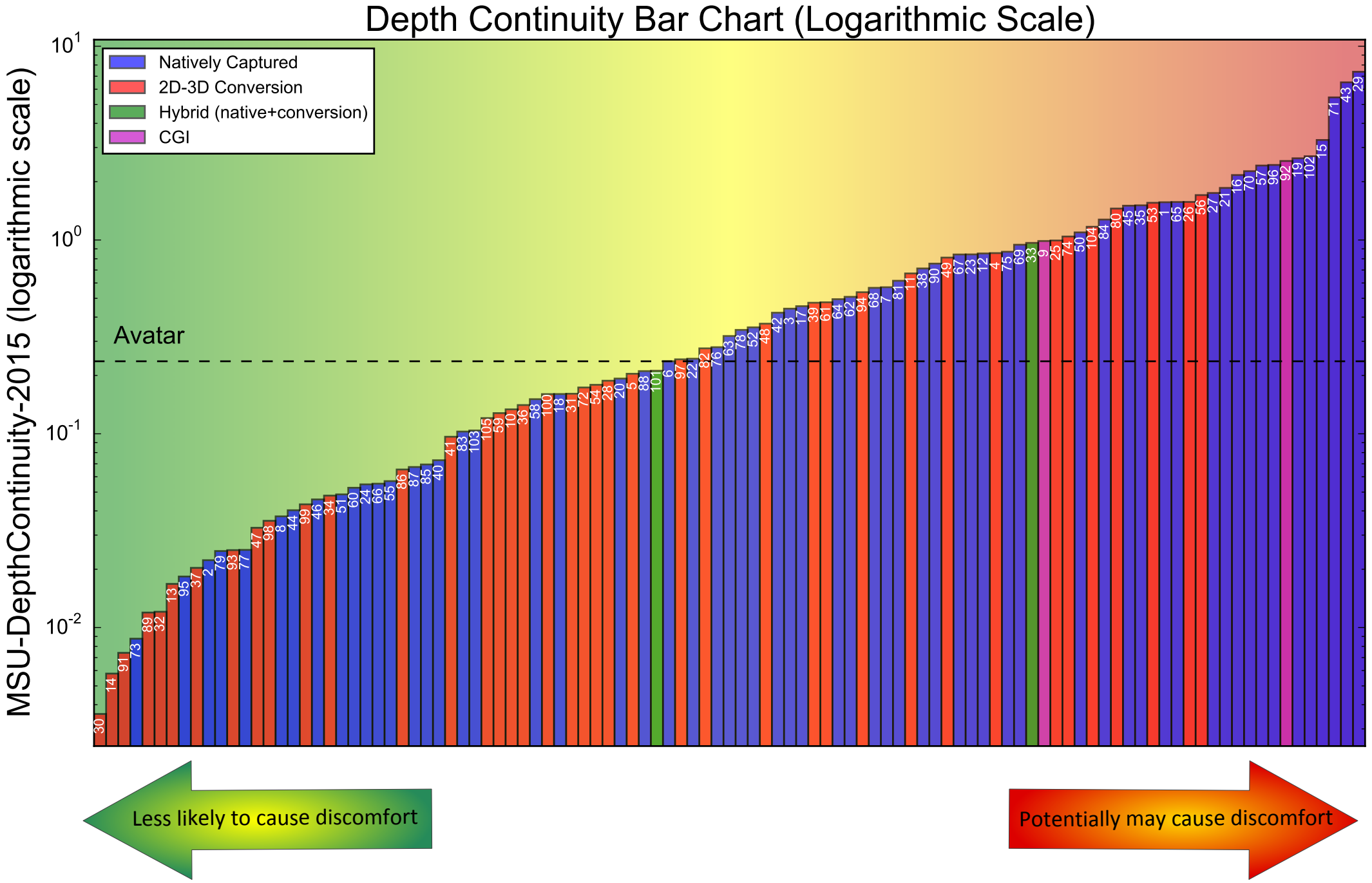


Figure 2.9a: Bar chart with movies sorted by depth continuity metric value in ascending order (logarithmic scale)

2.3 Vertical Parallax

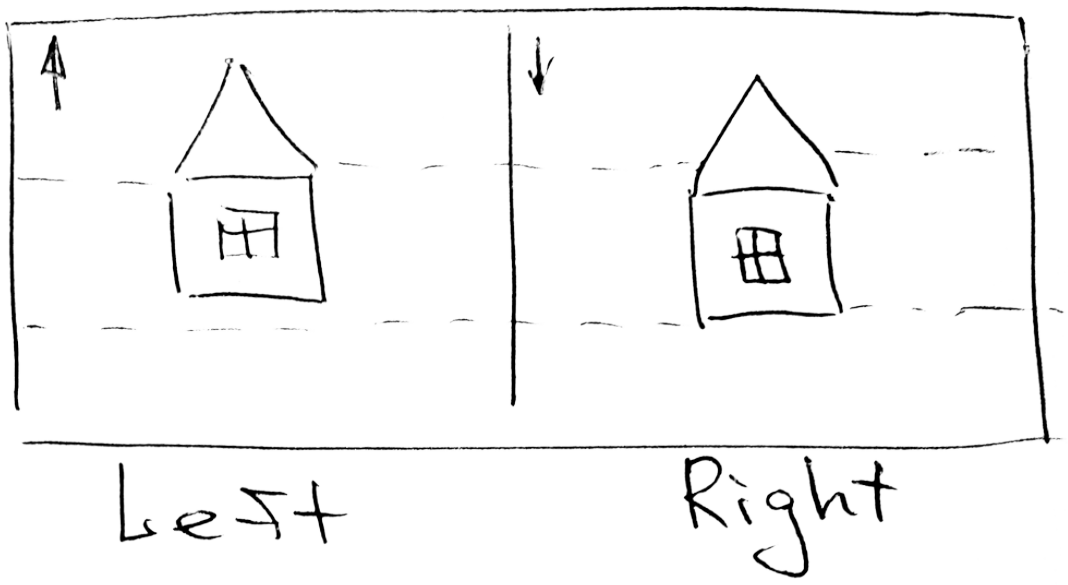


Figure 2.10: Schematic illustration of a stereo pair with vertical parallax

We provide two straightforward diagrams illustrating the average vertical-parallax metric values of each film relative to its release date and budget. The ranking by average vertical parallax is clearer in the following bar chart: vertical-disparity distributions appear in a stacked bar chart that sorts movies by the number of scenes with significant vertical parallax. Here we measure vertical parallax in permil of the frame width (0.5‰equals one pixel in Full HD). Our decision to use frame width may seem counterintuitive, however. Generally, most video captured nowadays has a wide aspect ratio — that is, 16:9 or greater. Nearly all home-cinema displays also have a 16:9 ratio. Thus, an examination of Blu-ray 3D releases for home cinemas should use the frame width; the vertical-parallax value then corresponds to the actual display size. A more thorough description of this metric appears in [12].

Worth noting is that vertical parallax — which is ostensibly specific to natively captured S3D movies — also occurs in movies converted to S3D format during postproduction. Our reports dedicated to analyzing 2D-to-3D conversion provide several examples [3, 5].

See Vertical Parallax Examples in Our Previous Reports (889 pages and 1139 figures in reports dedicated to native S3D, 689 pages and 740 figures in reports dedicated to 2D-3D conversion)

A lot of vertical parallax examples in captured movies (230 figures in total) and per-frame analysis charts can be found here:

- MSU VQMT3D Report 1 (March 2013, 246 pages, 295 figures) [1]
- MSU VQMT3D Report 2 (May 2013, 342 pages, 442 figures) [2]
- MSU VQMT3D Report 4 (October 2013, 301 pages, 402 figures) [4]

Several examples of vertical parallax in 2D-3D conversion (44 figures in total) can be found here:

- MSU VQMT3D Report 3 (August 2013, 305 pages, 336 figures) [3]
- MSU VQMT3D Report 5 (April 2014, 384 pages, 404 figures) [5]

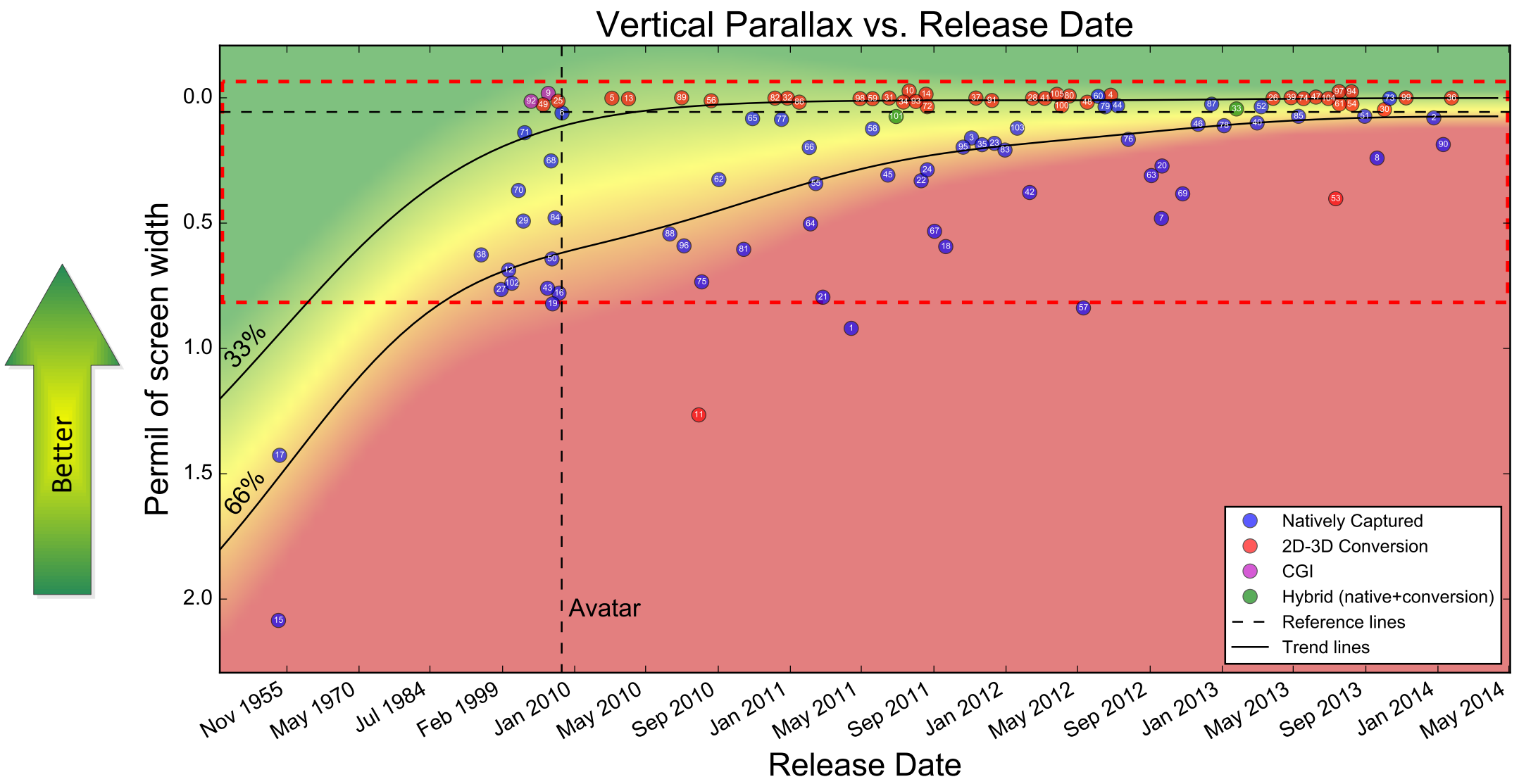


Figure 2.11: Diagram illustrating vertical parallax metric value relative to movie release date

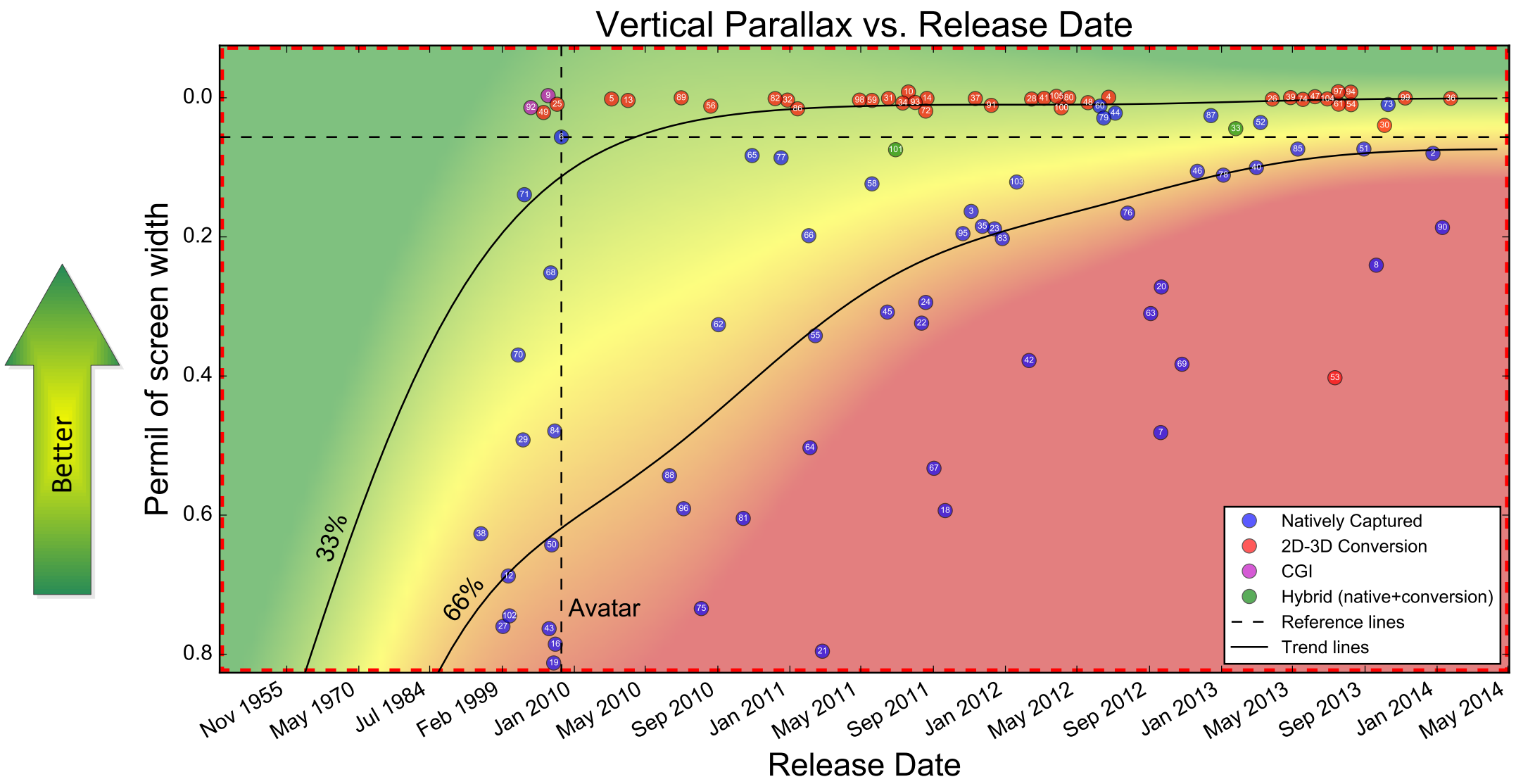


Figure 2.11a: Magnified fragment of the diagram in Figure 2.11

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

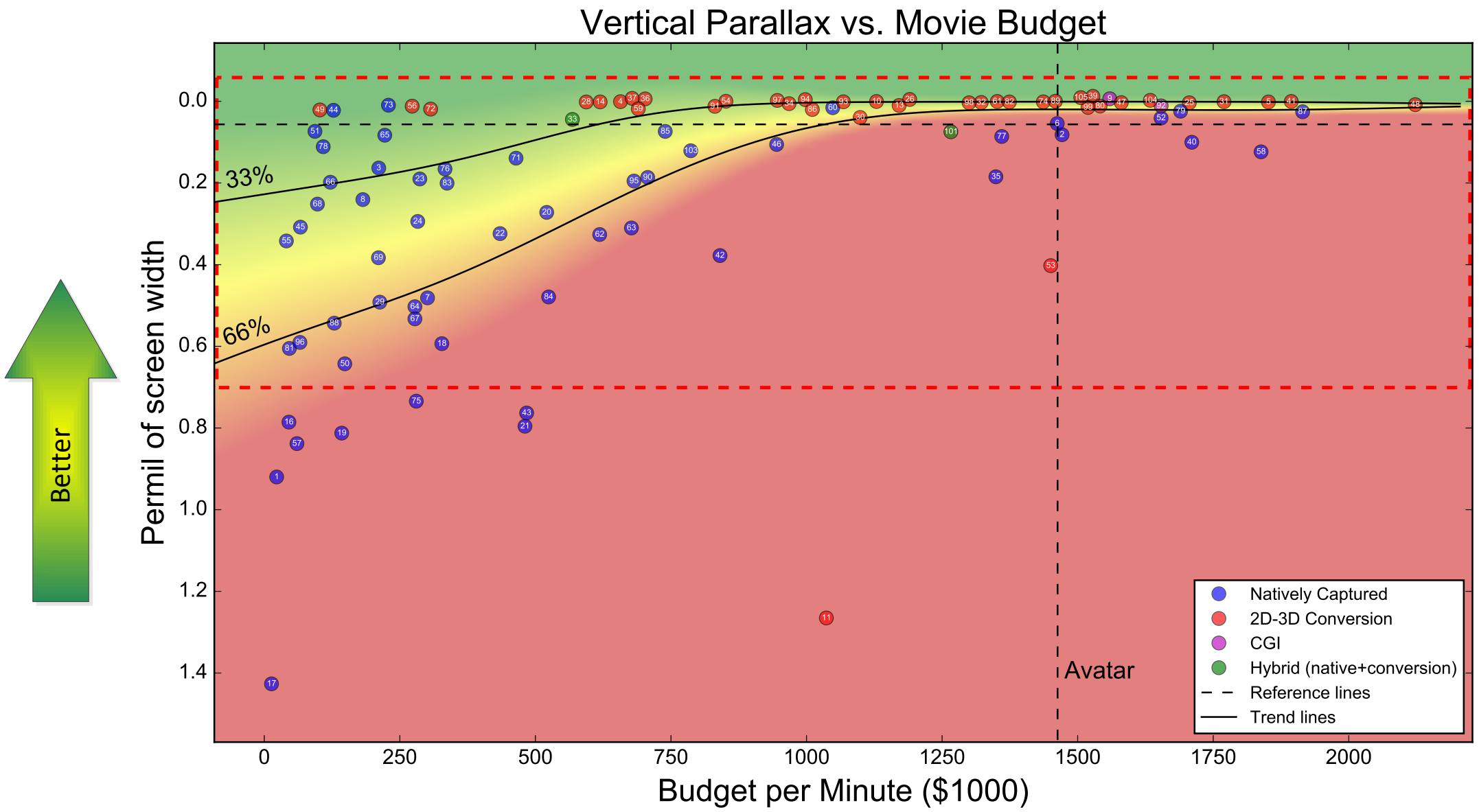


Figure 2.12: Diagram illustrating vertical parallax metric value relative to movie budget (per minute)

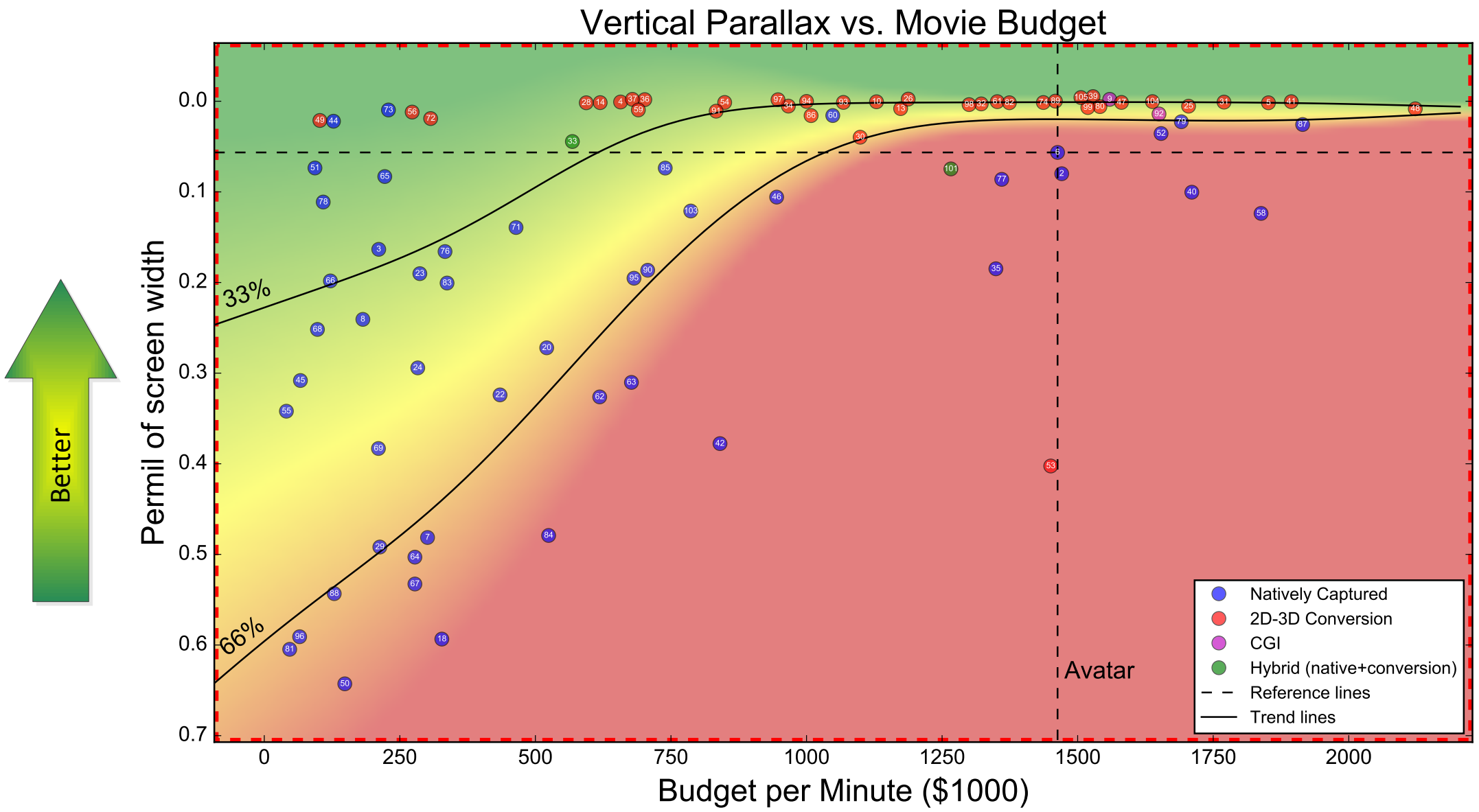


Figure 2.12a: Magnified fragment of the diagram in Figure 2.12

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

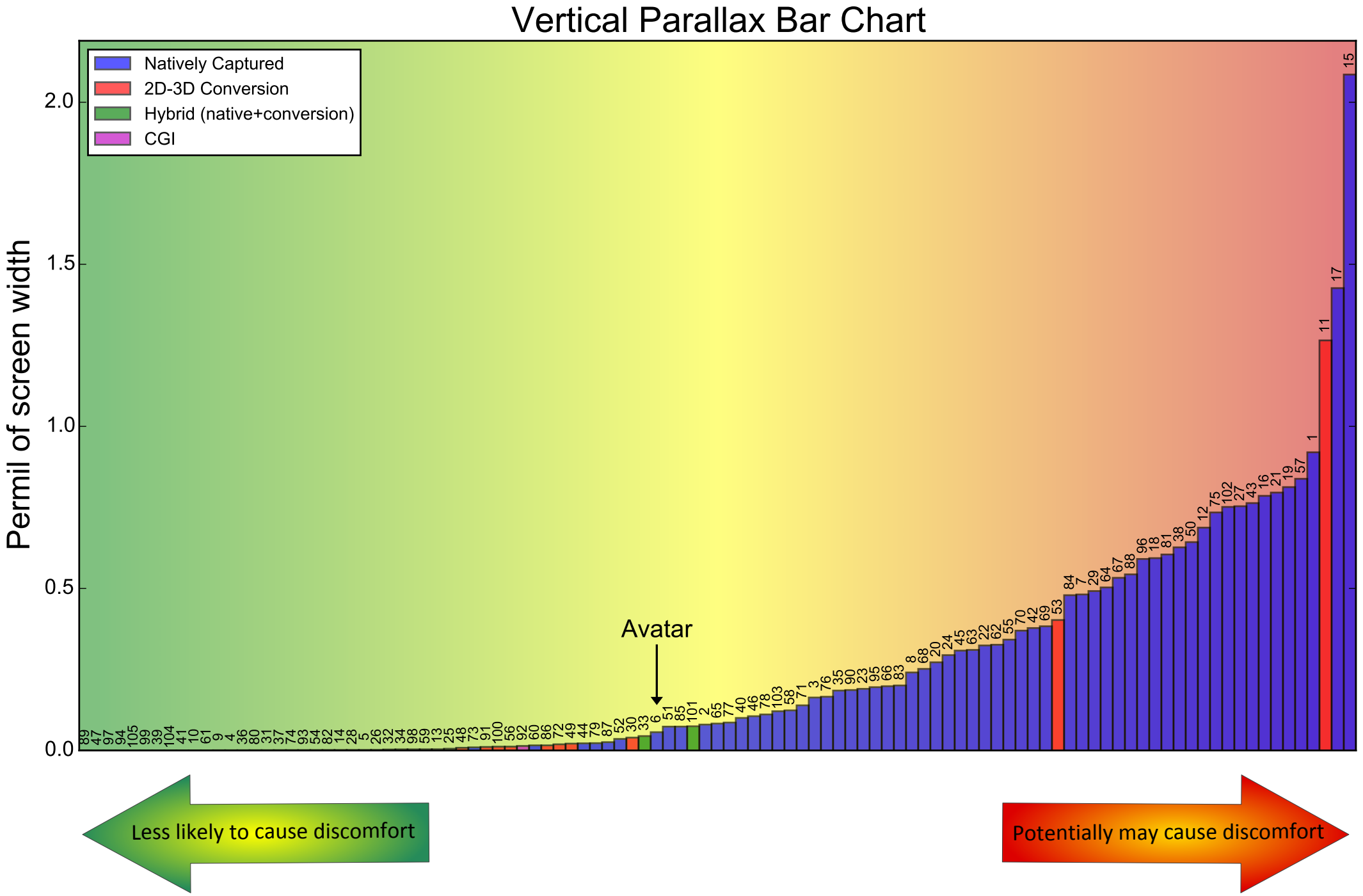


Figure 2.13: Bar chart with movies sorted by average vertical parallax metric value in ascending order

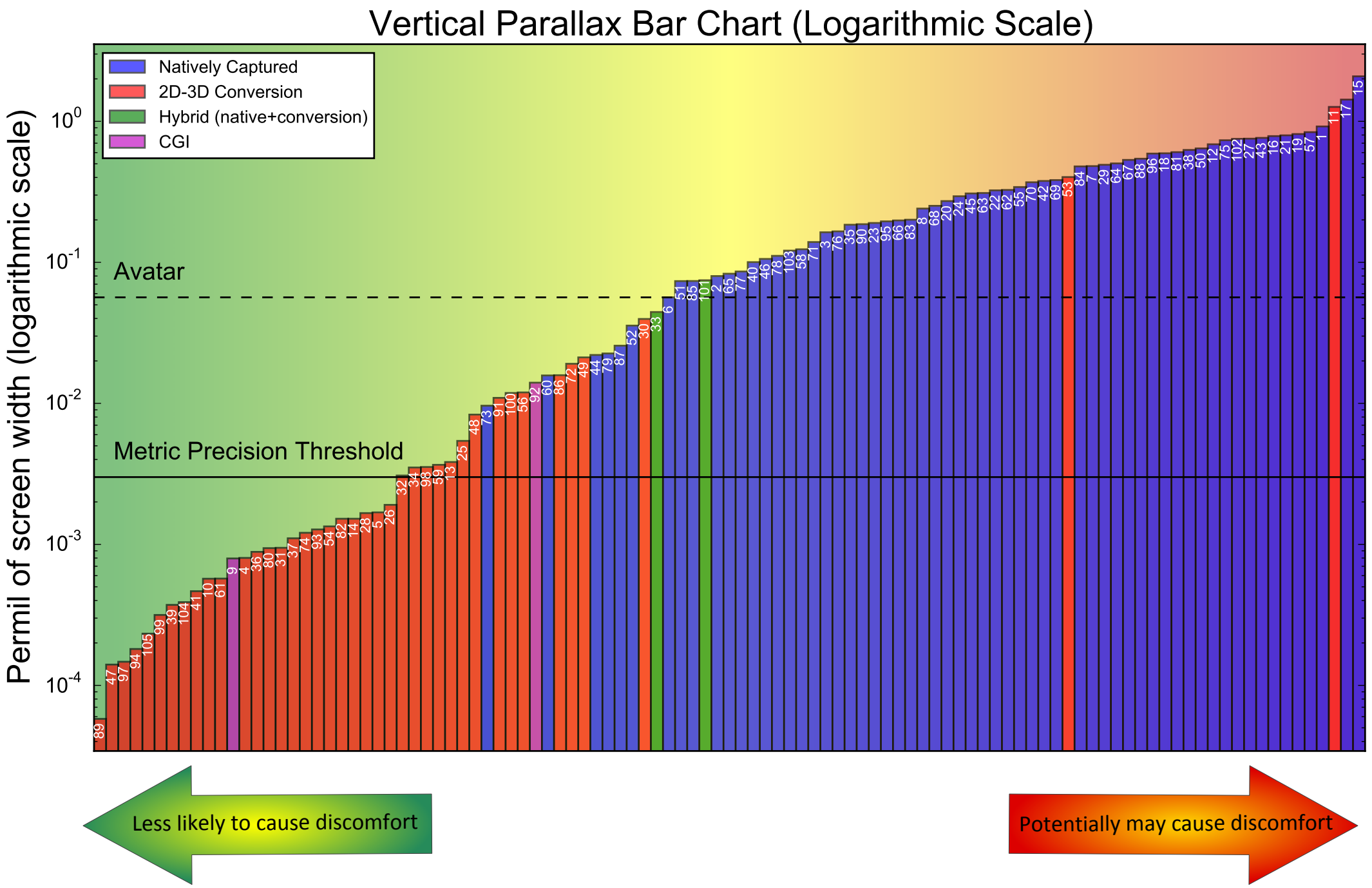


Figure 2.13a: Bar chart with movies sorted by average vertical parallax metric value in ascending order (logarithmic scale)

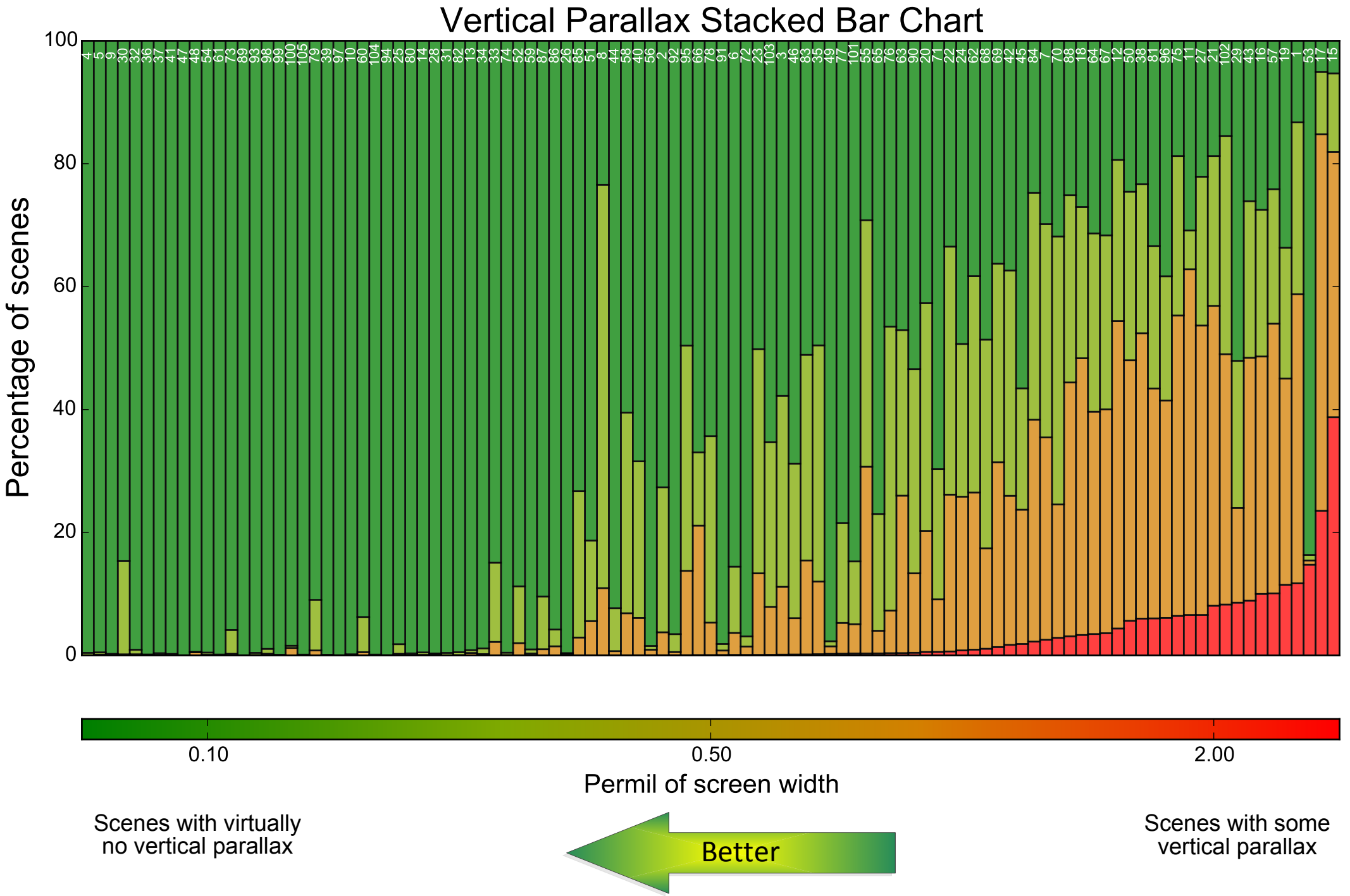
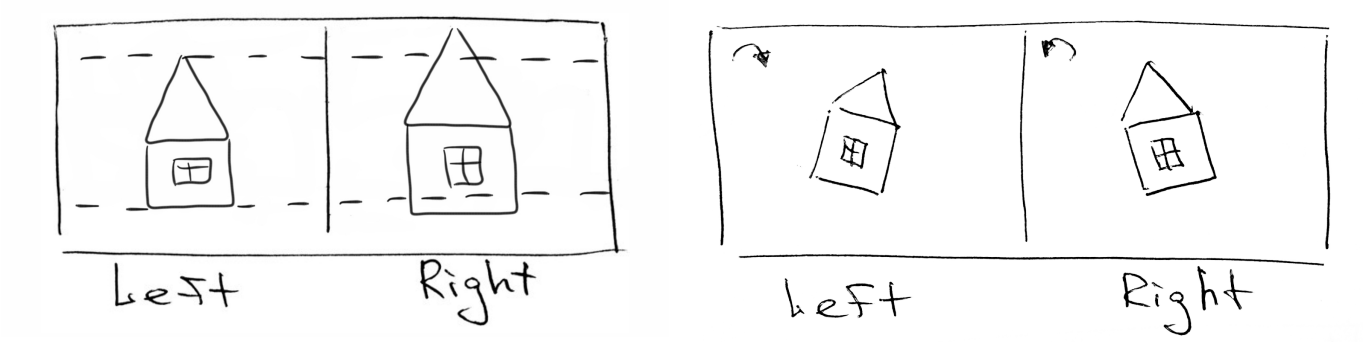


Figure 2.14: Stacked bar chart with movies sorted by the amount of low-technical-quality scenes

2.4 Scale and Rotation Mismatch



(a) Scale mismatch

(b) Rotation mismatch

Figure 2.15: Schematic illustration of stereopairs with scale and rotation mismatch

Taking into account a wider range of geometric inconsistencies, we also provide an overall film comparison in terms of scale and rotation mismatch. It includes the same set of diagrams as in the previous section (Vertical Parallax).

We measure scale mismatch as a percentage. For example, if the metric value is 0.3, the image in the right view is $1.003\times$ "bigger" than the image in the left view. We measure rotation mismatch in degrees.

Scale and rotation mismatch also occasionally arise in 2D-to-3D conversion; examples appear in our eighth VQMT3D report [8].

See Scale/Rotation Mismatch Examples in Our Previous Reports
A lot of scale/rotation mismatch examples in captured movies (249 figures in total) and several in converted movies (18 figures in total) alongside with per-frame analysis charts can be found here:

- MSU VQMT3D Report 8 (June 2015, 366 pages, 361 figures) [8]

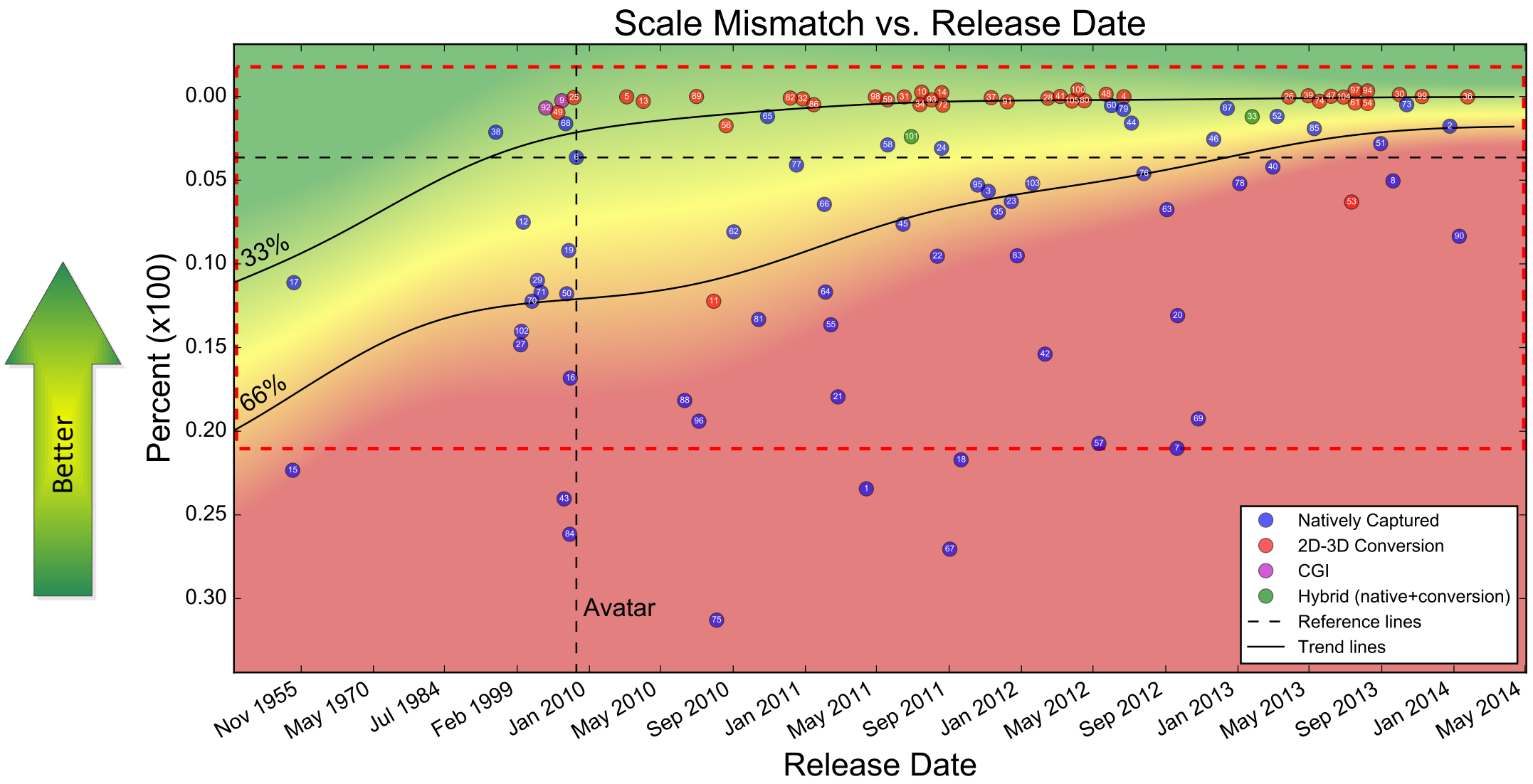


Figure 2.16: Diagram illustrating scale mismatch metric value relative to movie release date

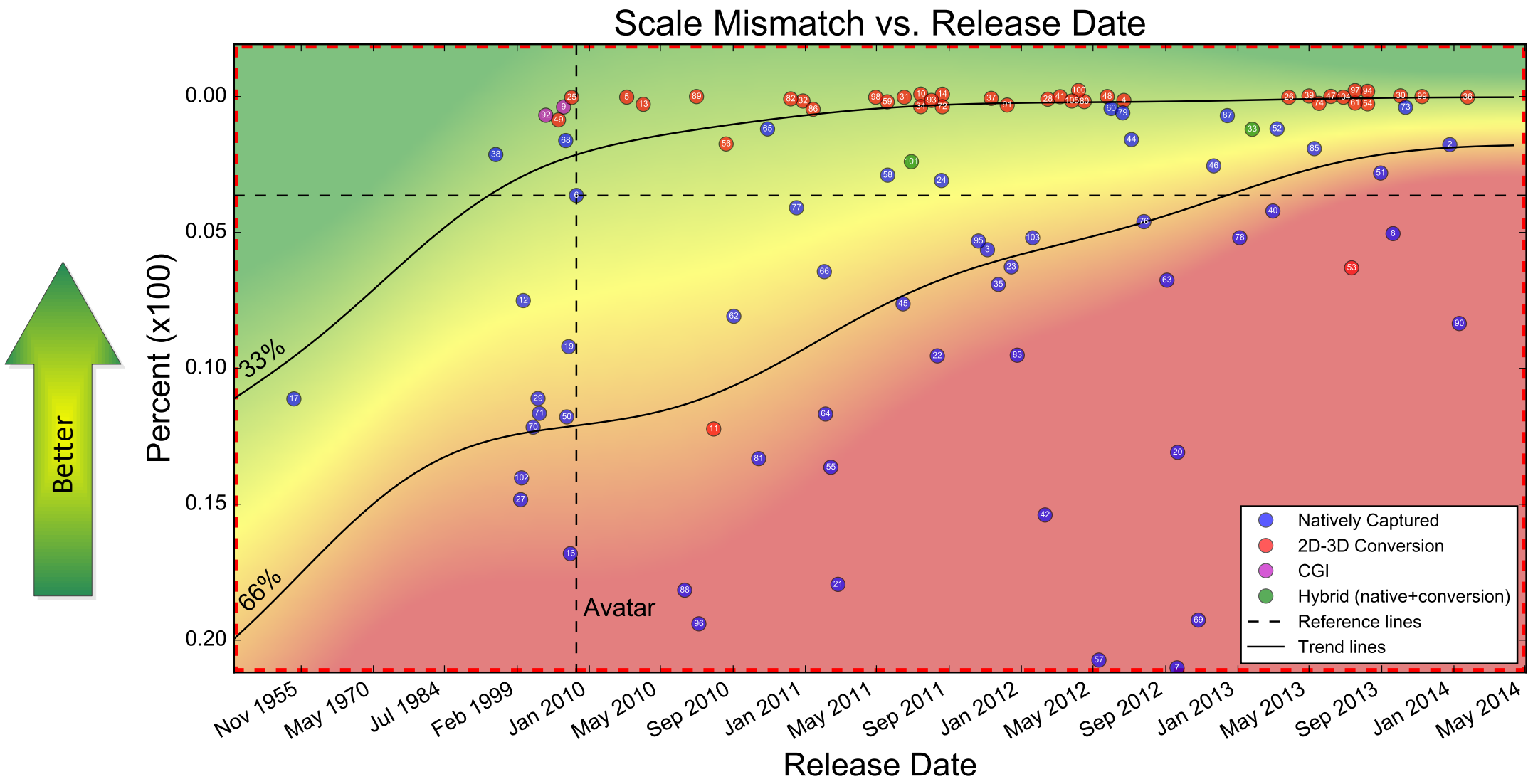


Figure 2.16a: Magnified fragment of the diagram in Figure 2.16

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

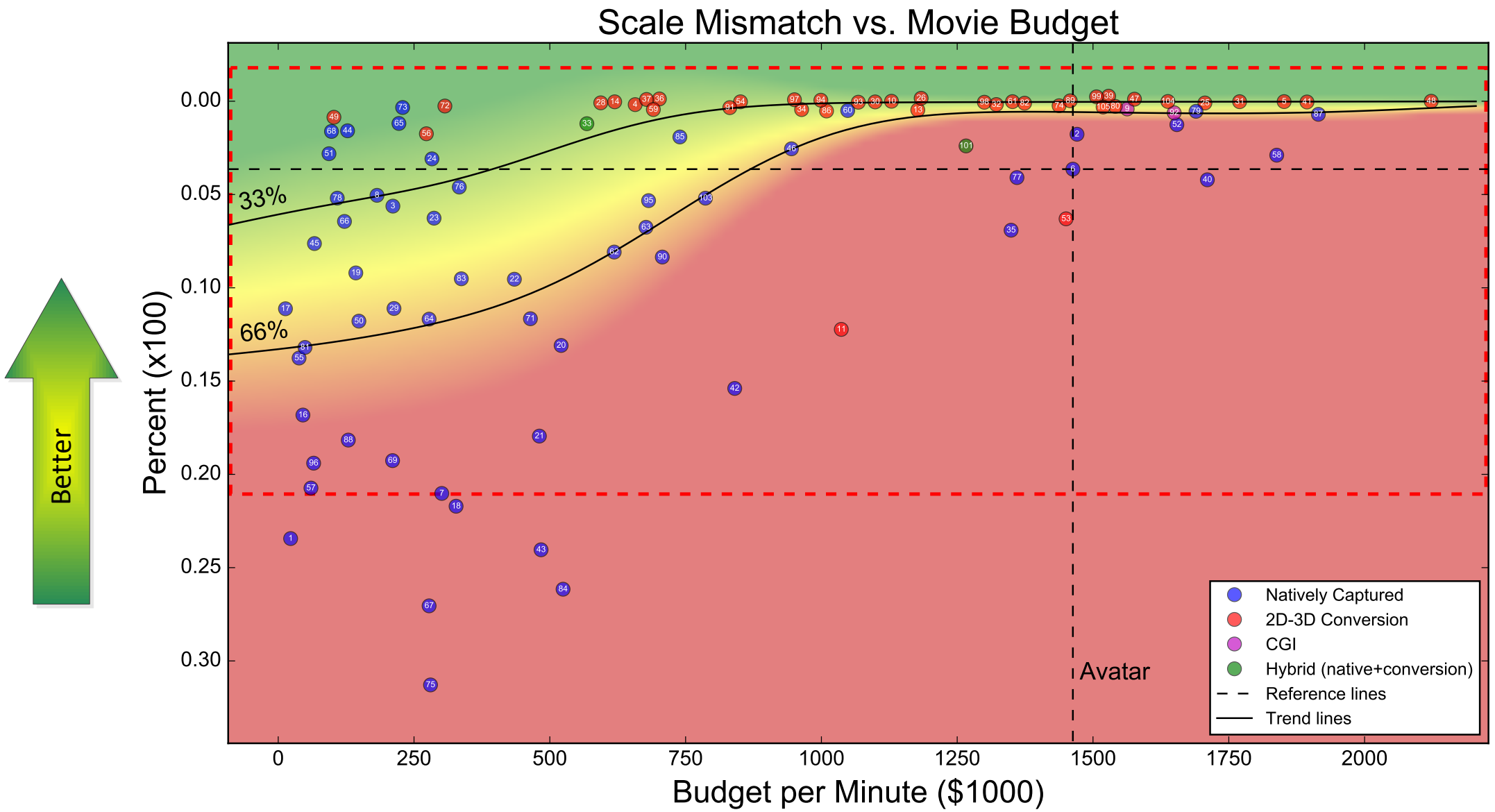


Figure 2.17: Diagram illustrating scale mismatch metric value relative to movie budget (per minute)

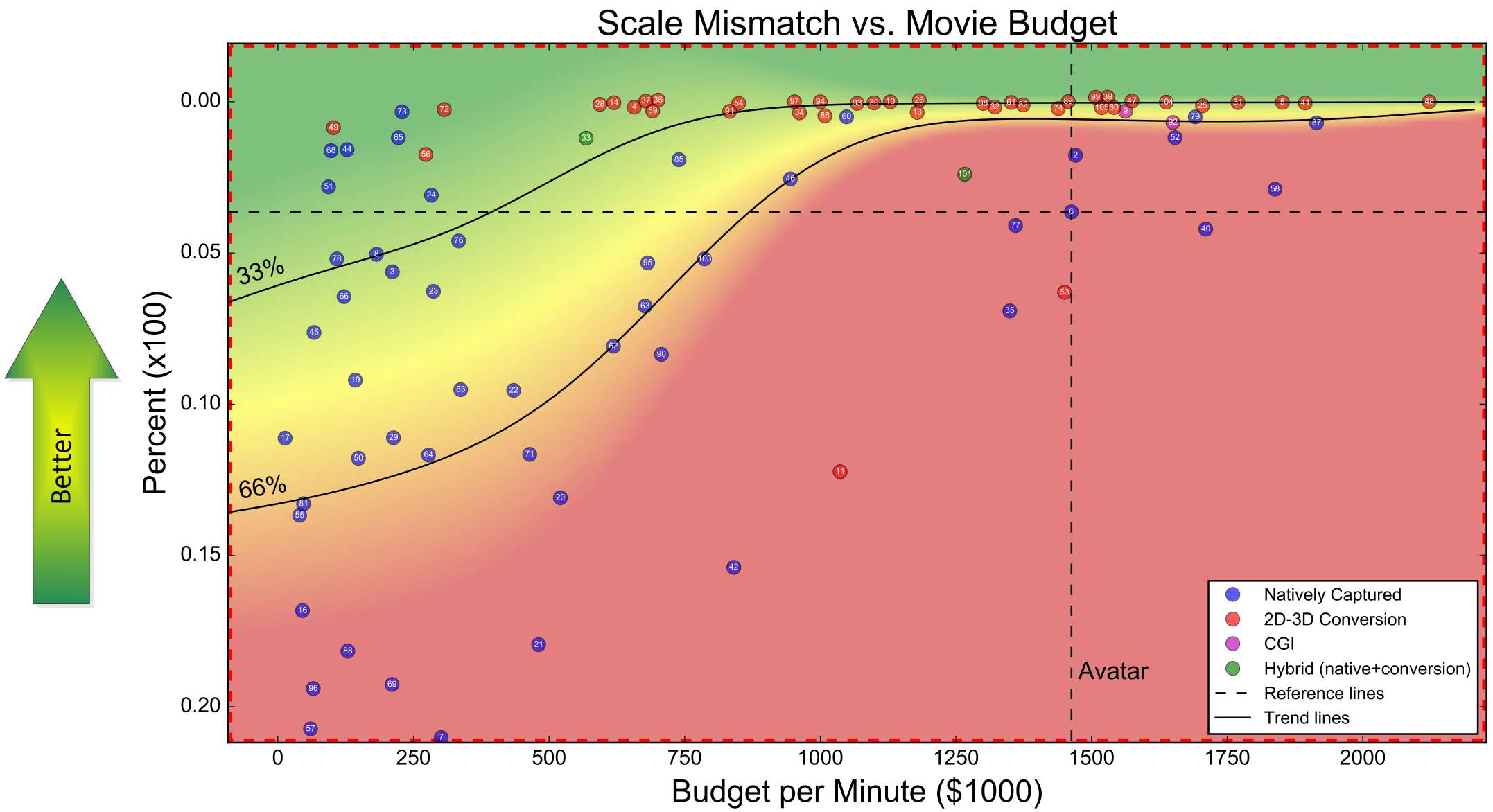


Figure 2.17a: Magnified fragment of the diagram in Figure 2.17

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

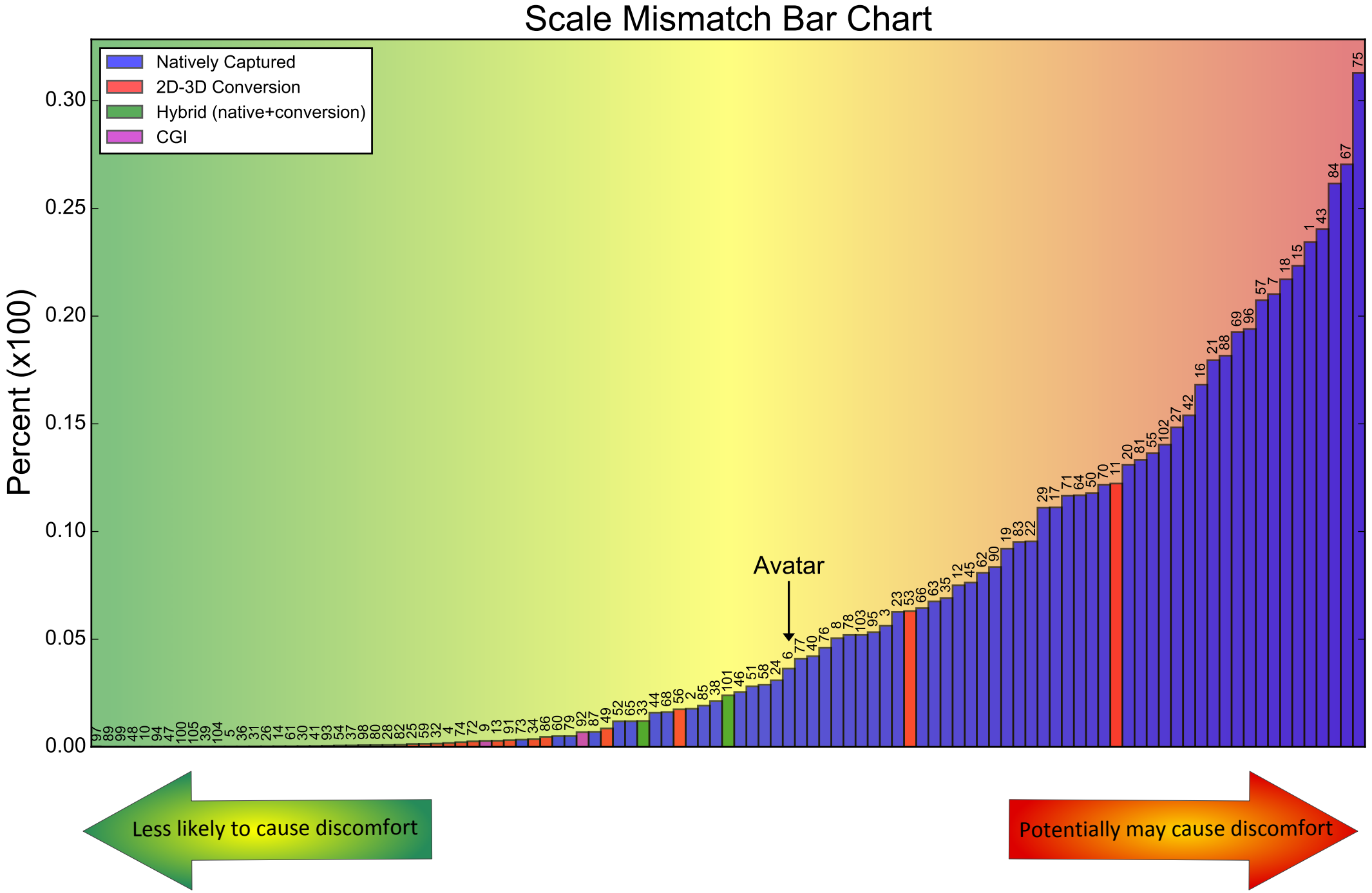


Figure 2.18: Bar chart with movies sorted by average scale mismatch metric value in ascending order

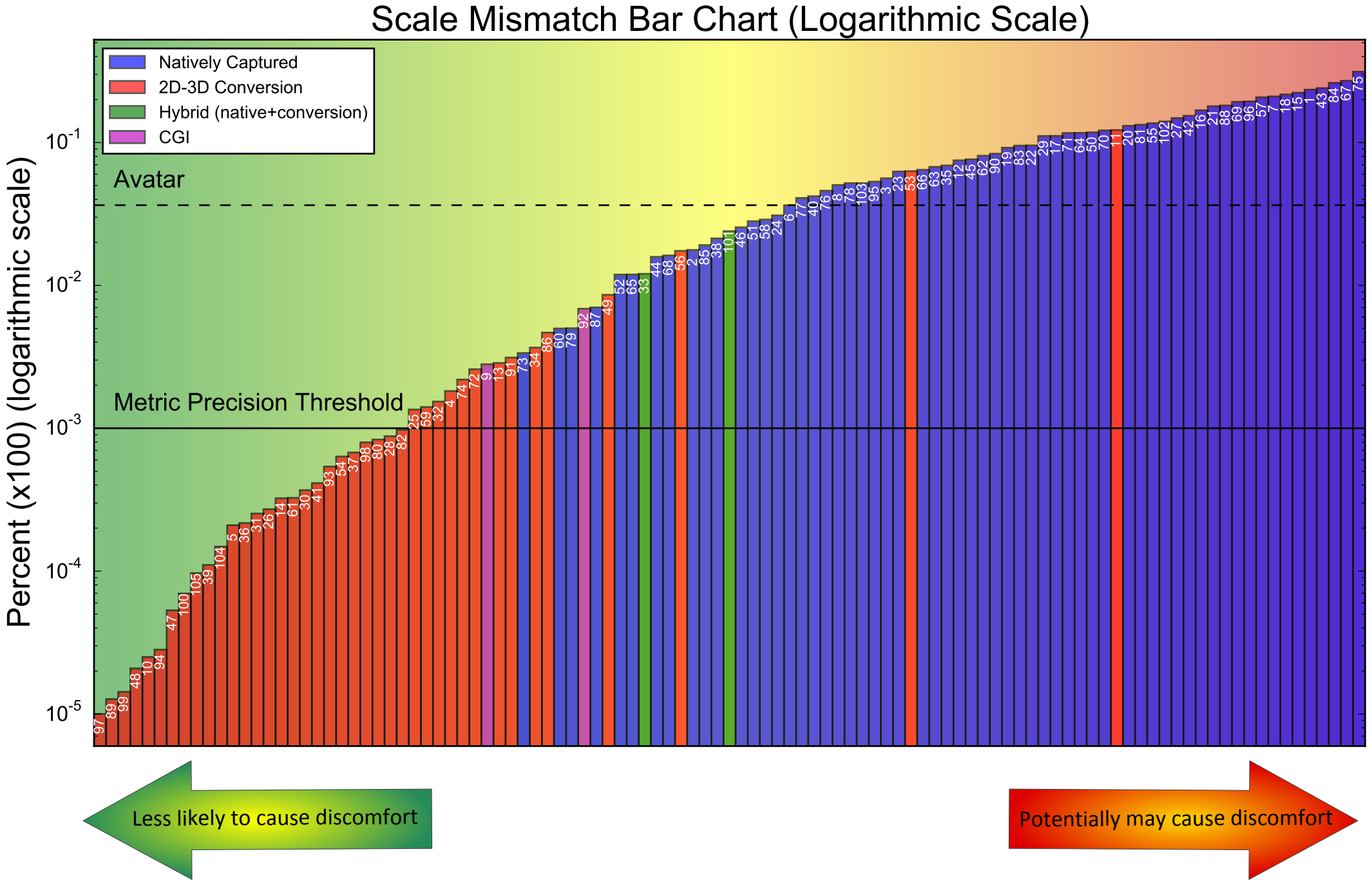


Figure 2.18a: Bar chart with movies sorted by average scale mismatch metric value in ascending order (logarithmic scale)

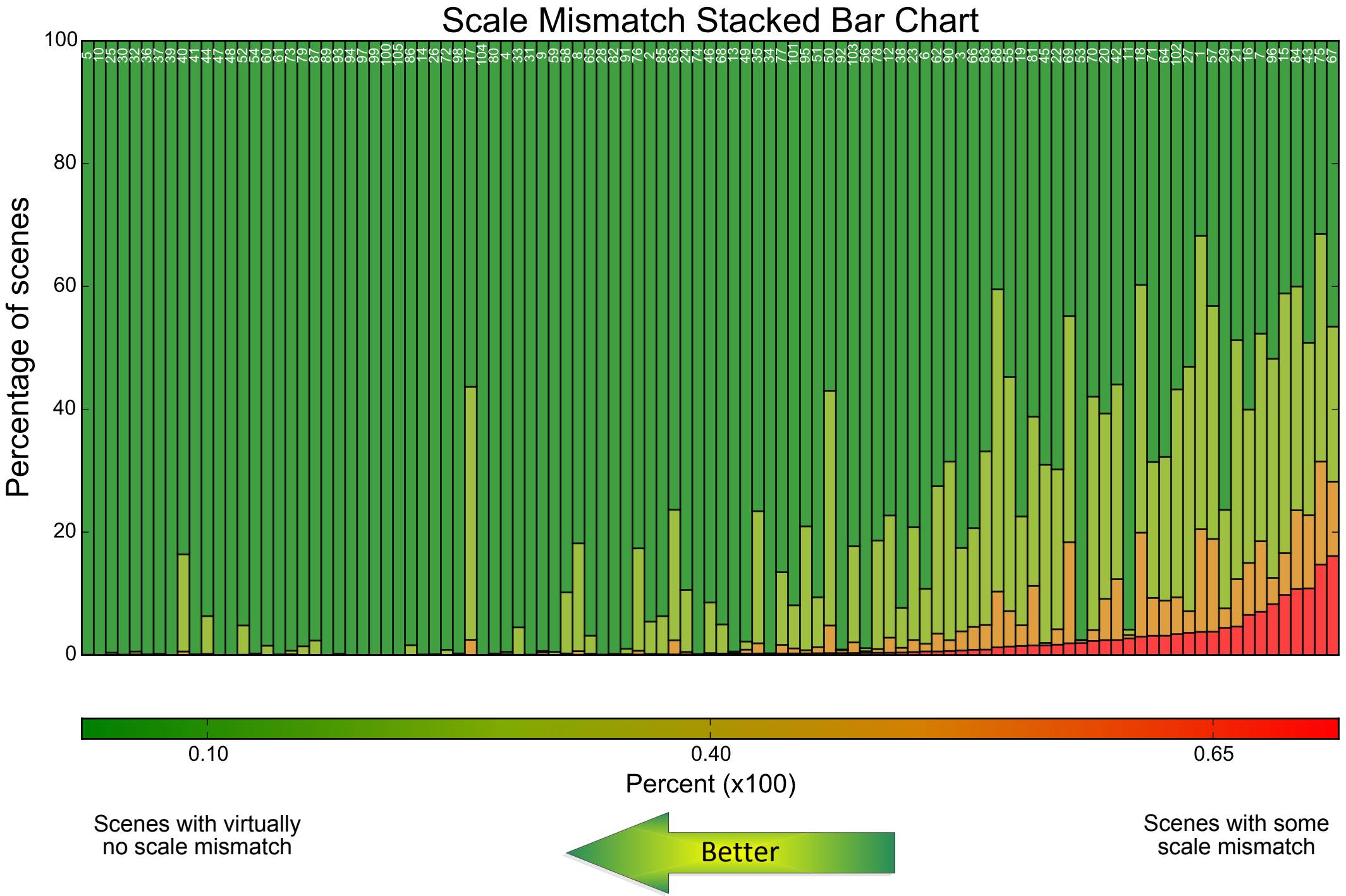


Figure 2.19: Stacked bar chart with movies sorted by the amount of low-technical-quality scenes

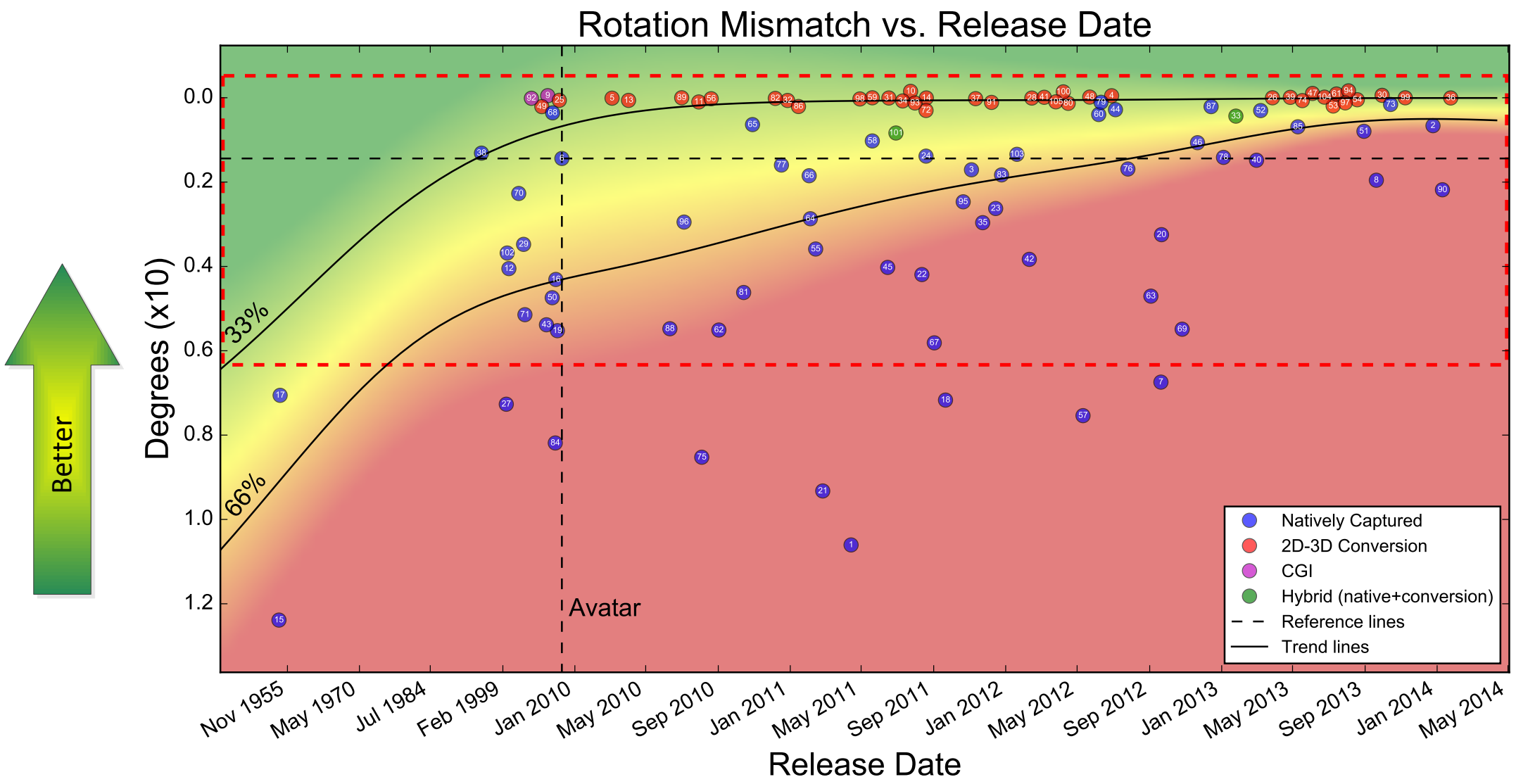


Figure 2.20: Diagram illustrating rotation mismatch metric value relative to movie release date

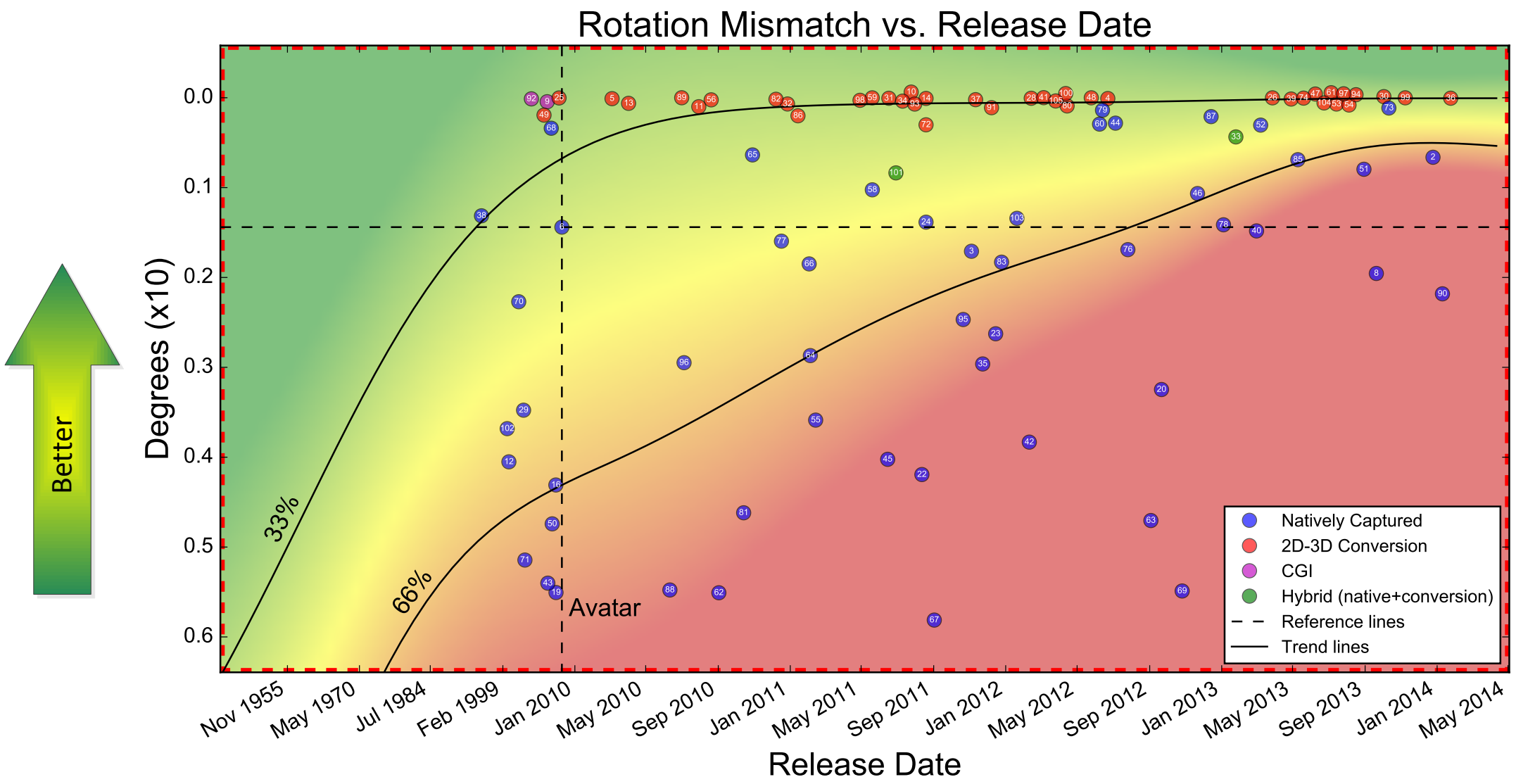


Figure 2.20a: Magnified fragment of the diagram in Figure 2.20

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

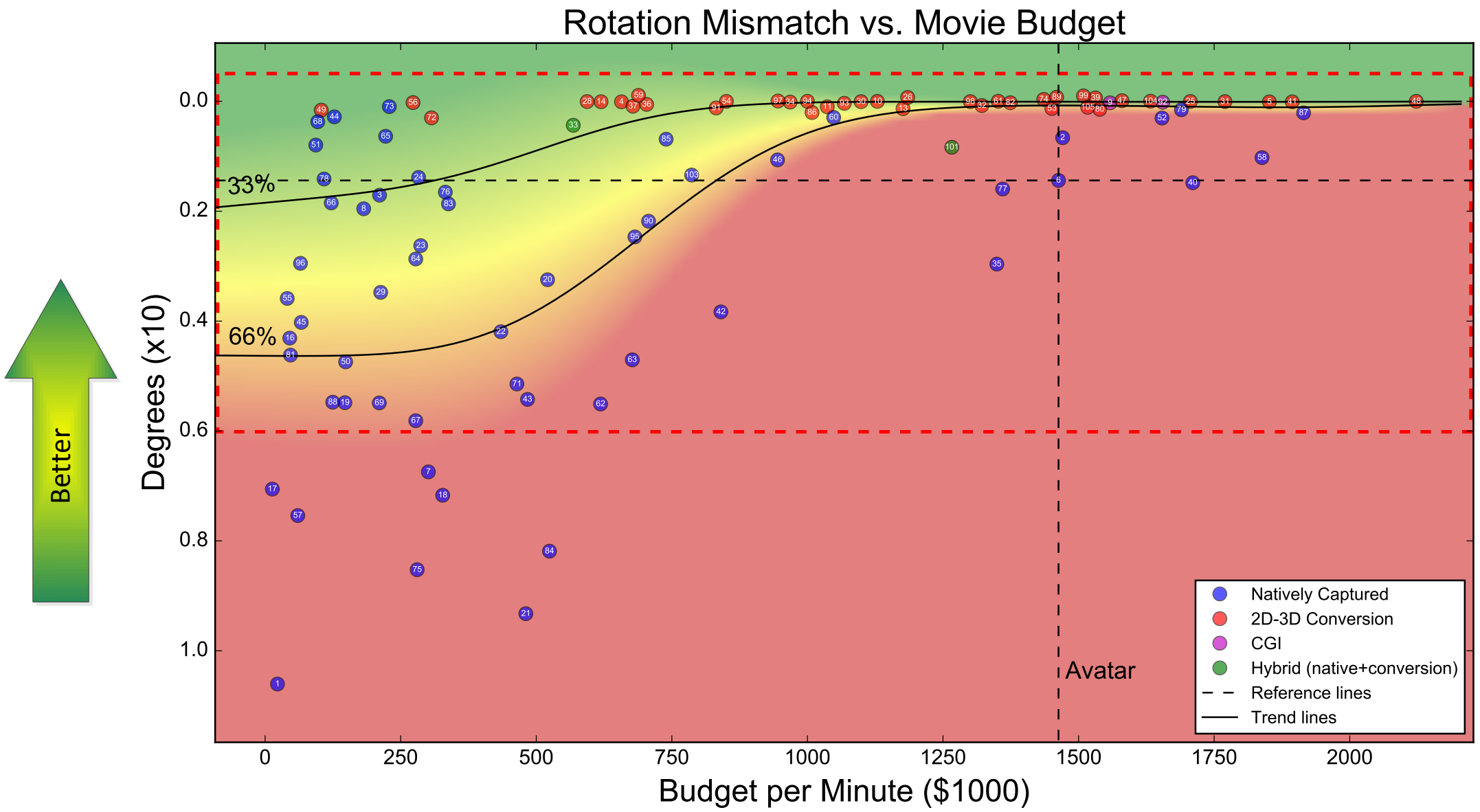


Figure 2.21: Diagram illustrating rotation mismatch metric value relative to movie budget (per minute)

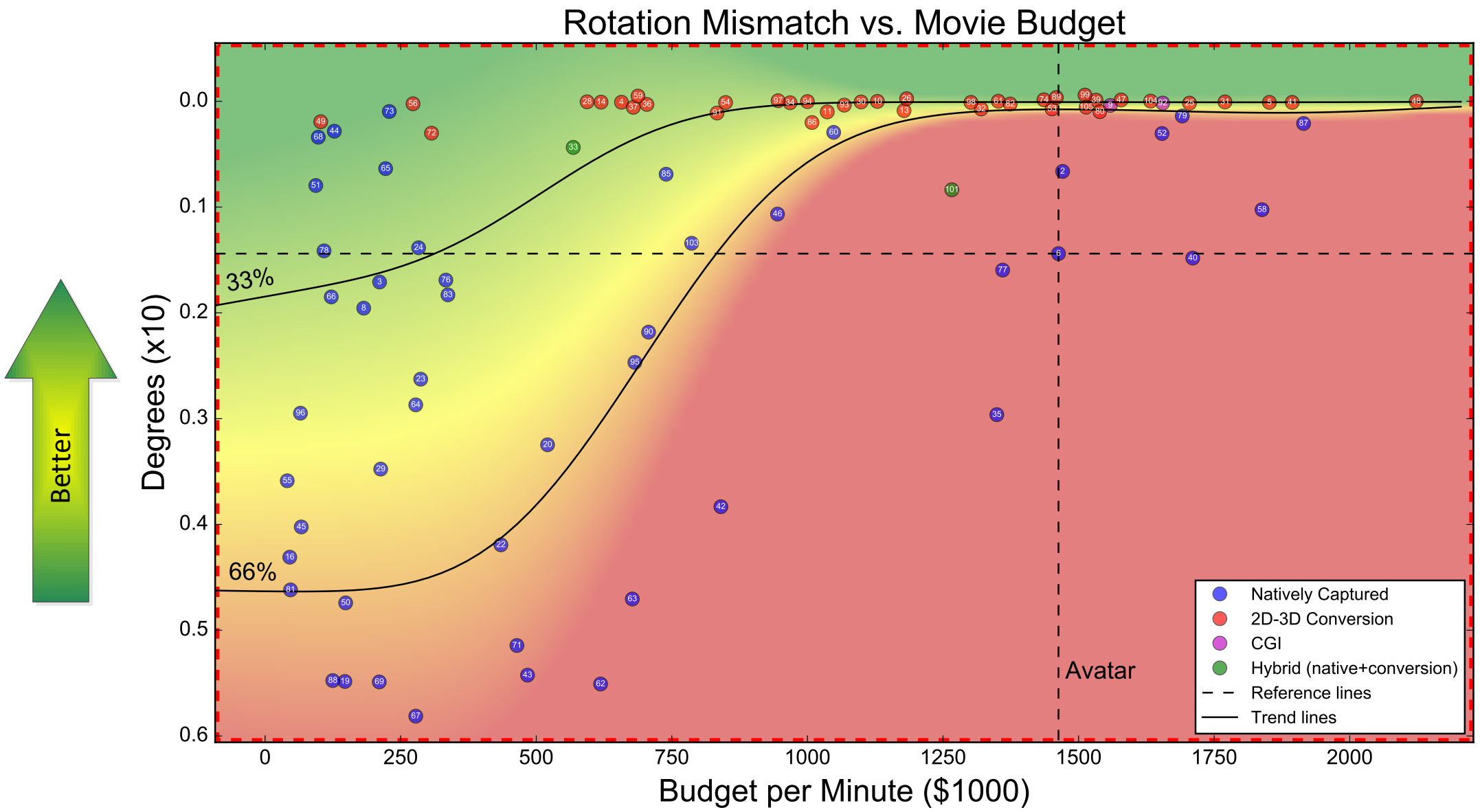


Figure 2.21a: Magnified fragment of the diagram in Figure 2.21

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

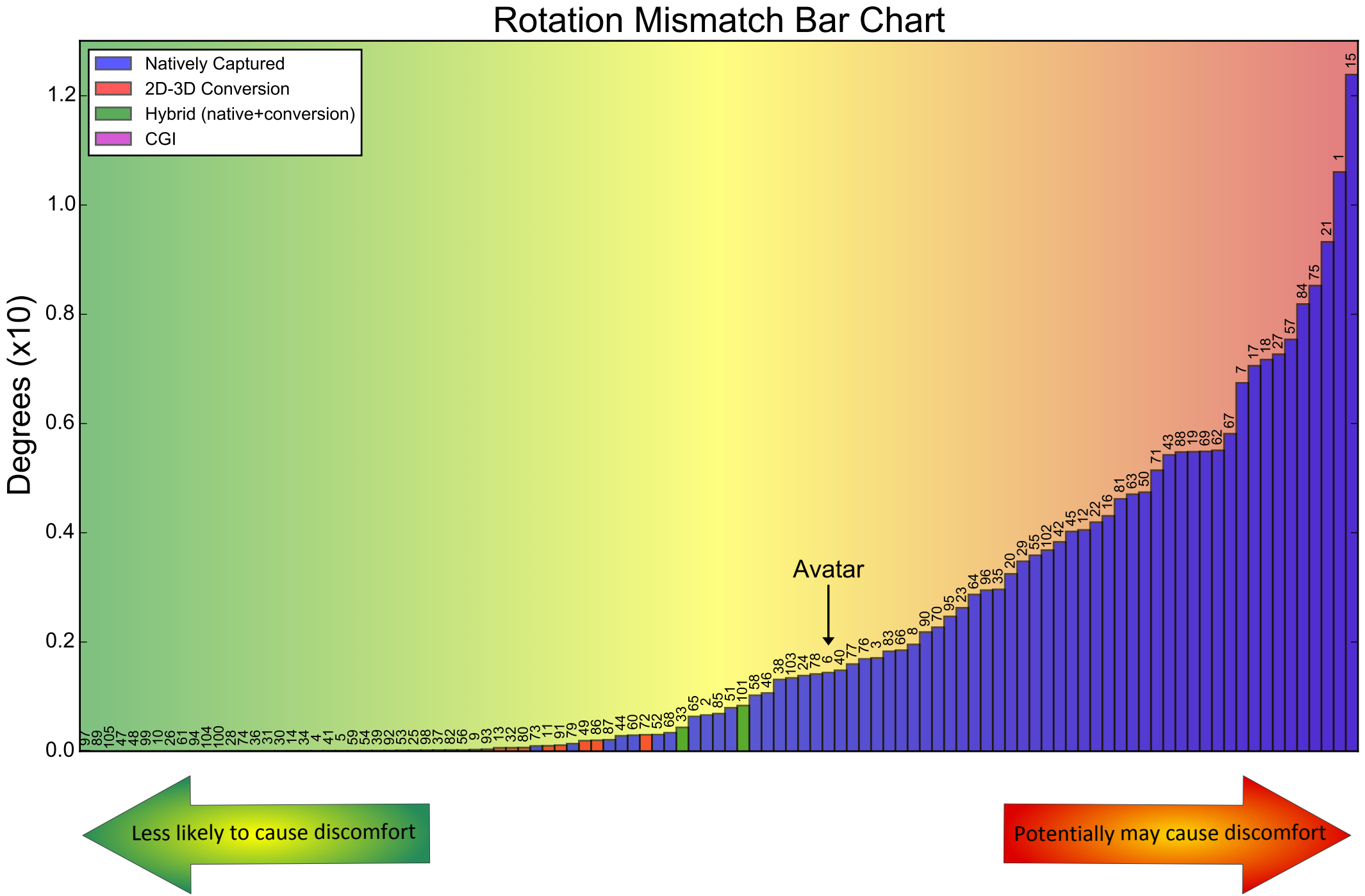


Figure 2.22: Bar chart with movies sorted by average rotation mismatch metric value in ascending order

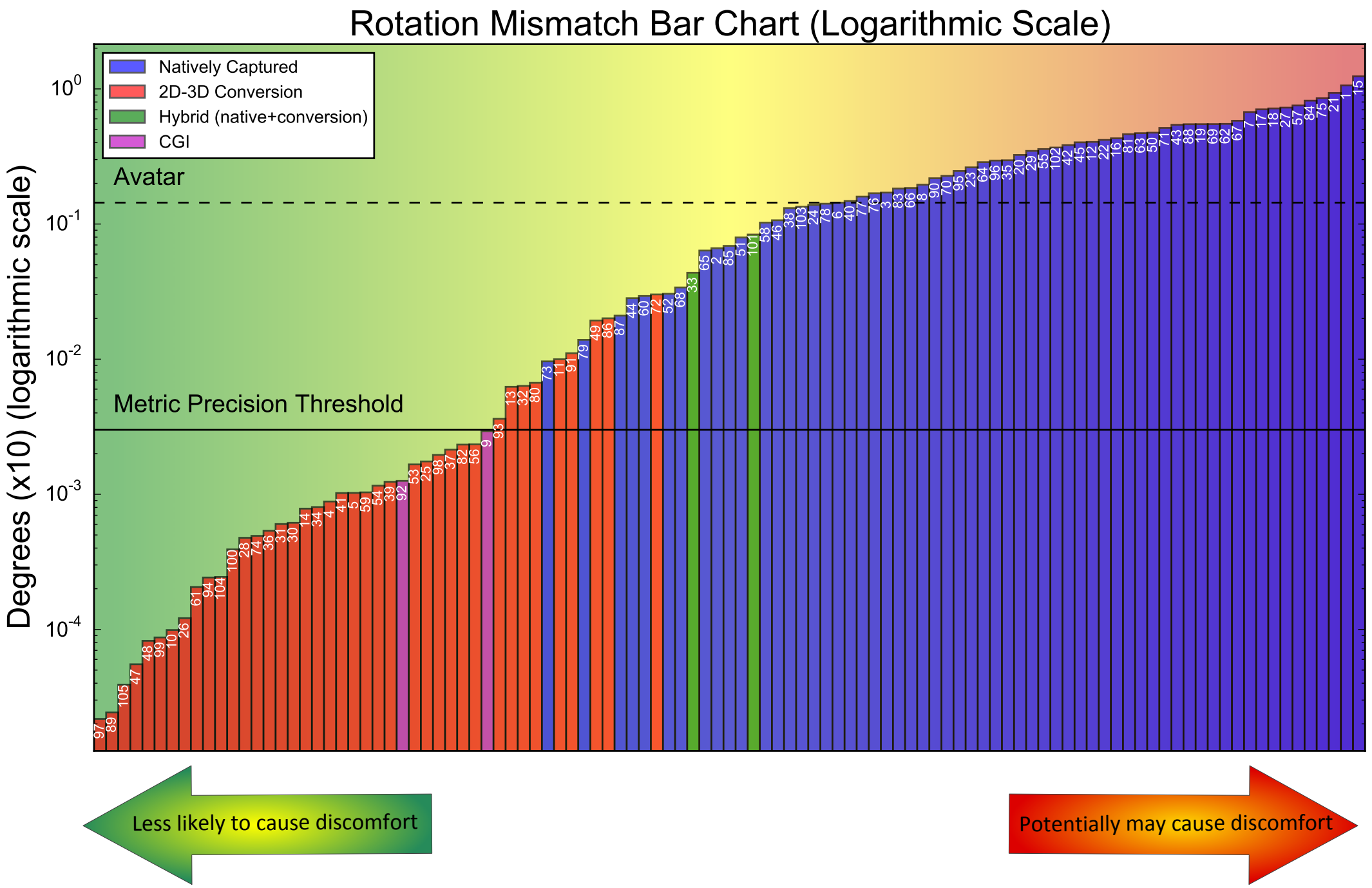


Figure 2.22a: Bar chart with movies sorted by average rotation mismatch metric value in ascending order (logarithmic scale)

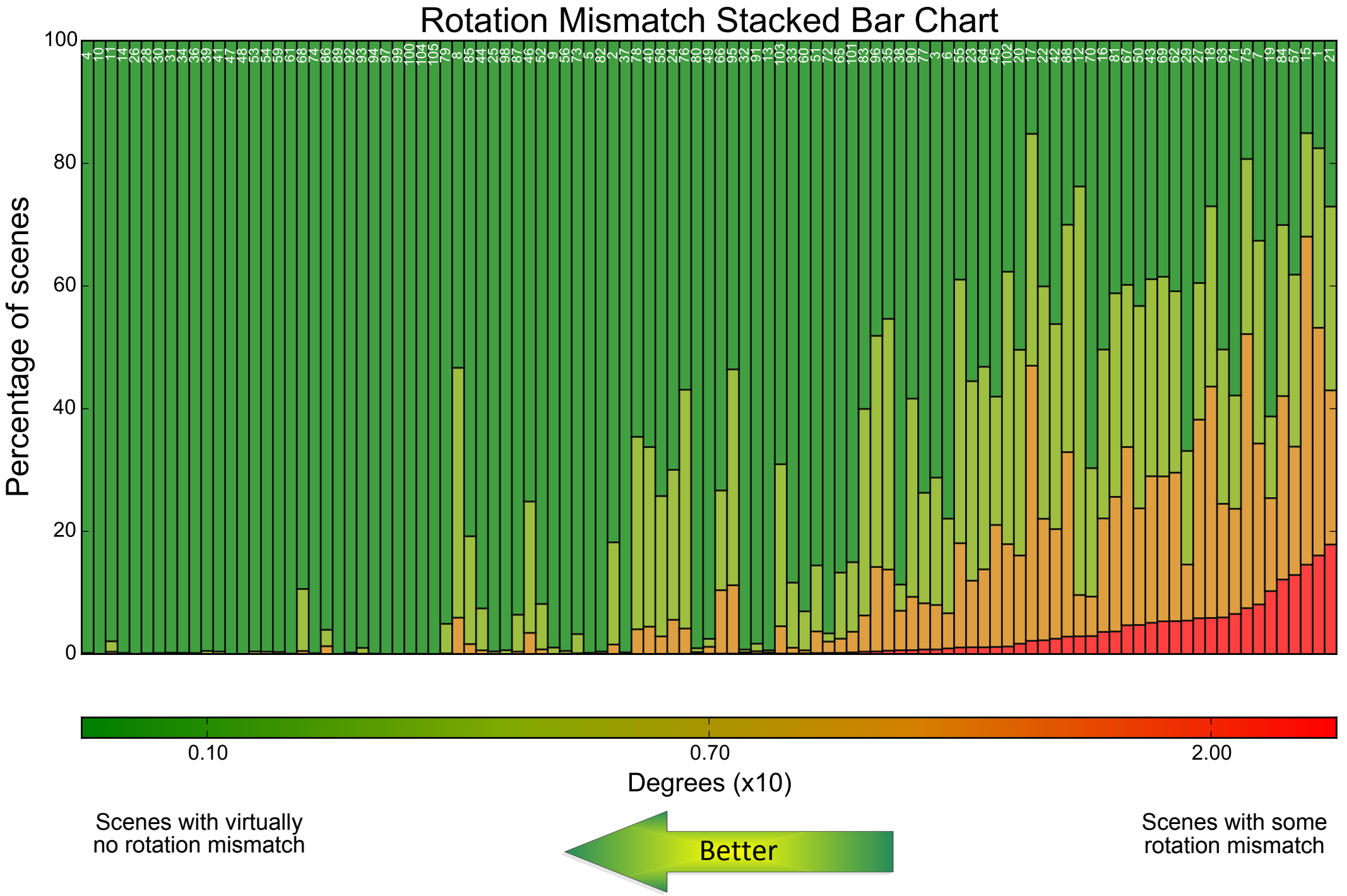


Figure 2.23: Stacked bar chart with movies sorted by the amount of low-technical-quality scenes

2.5 Color Mismatch

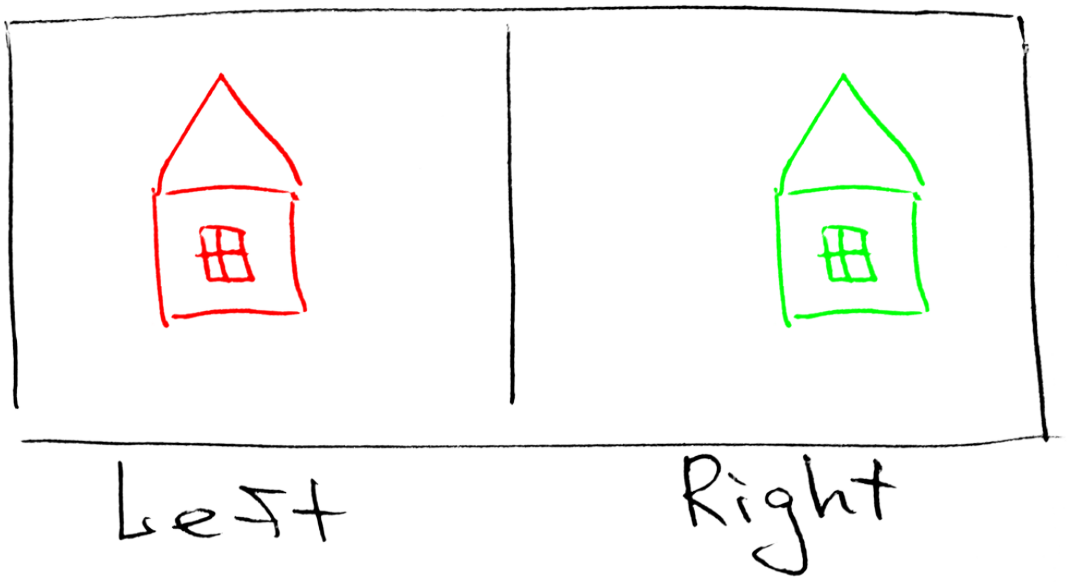


Figure 2.24: Schematic illustration of a stereo pair with color mismatch

As with vertical parallax, we provide for color mismatch two straightforward diagrams illustrating a movie's average metric value relative to its release date and budget, as well as a bar chart with average color-mismatch values and a stacked bar chart that sorts movies by number of scenes containing significant color mismatch. The color-mismatch values are dimensionless; the important thing is that we produced them using the MSU-3Dcolor-2011 metric. They represent the strength of the color difference between the two views of a stereoscopic frame. Higher values indicate greater color mismatch. A more thorough description of this metric appears in [9].

Owing to various errors introduced during postproduction, color mismatch can also arise in 2D-to-3D conversion. Our reports dedicated to analyzing 2D-to-3D conversion include several examples [3, 5].

See Color Mismatch Examples in Our Previous Reports (889 pages and 1139 figures in reports dedicated to native S3D, 689 pages and 740 figures in reports dedicated to 2D-3D conversion)

A lot of color mismatch examples in captured movies (416 figures in total) and per-frame analysis charts can be found here:

- MSU VQMT3D Report 1 (March 2013, 246 pages, 295 figures) [1]
- MSU VQMT3D Report 2 (May 2013, 342 pages, 442 figures) [2]
- MSU VQMT3D Report 4 (October 2013, 301 pages, 402 figures) [4]

Several examples of color mismatch in 2D-3D conversion (64 figures in total) can be found here:

- MSU VQMT3D Report 3 (August 2013, 305 pages, 336 figures) [3]
- MSU VQMT3D Report 5 (April 2014, 384 pages, 404 figures) [5]

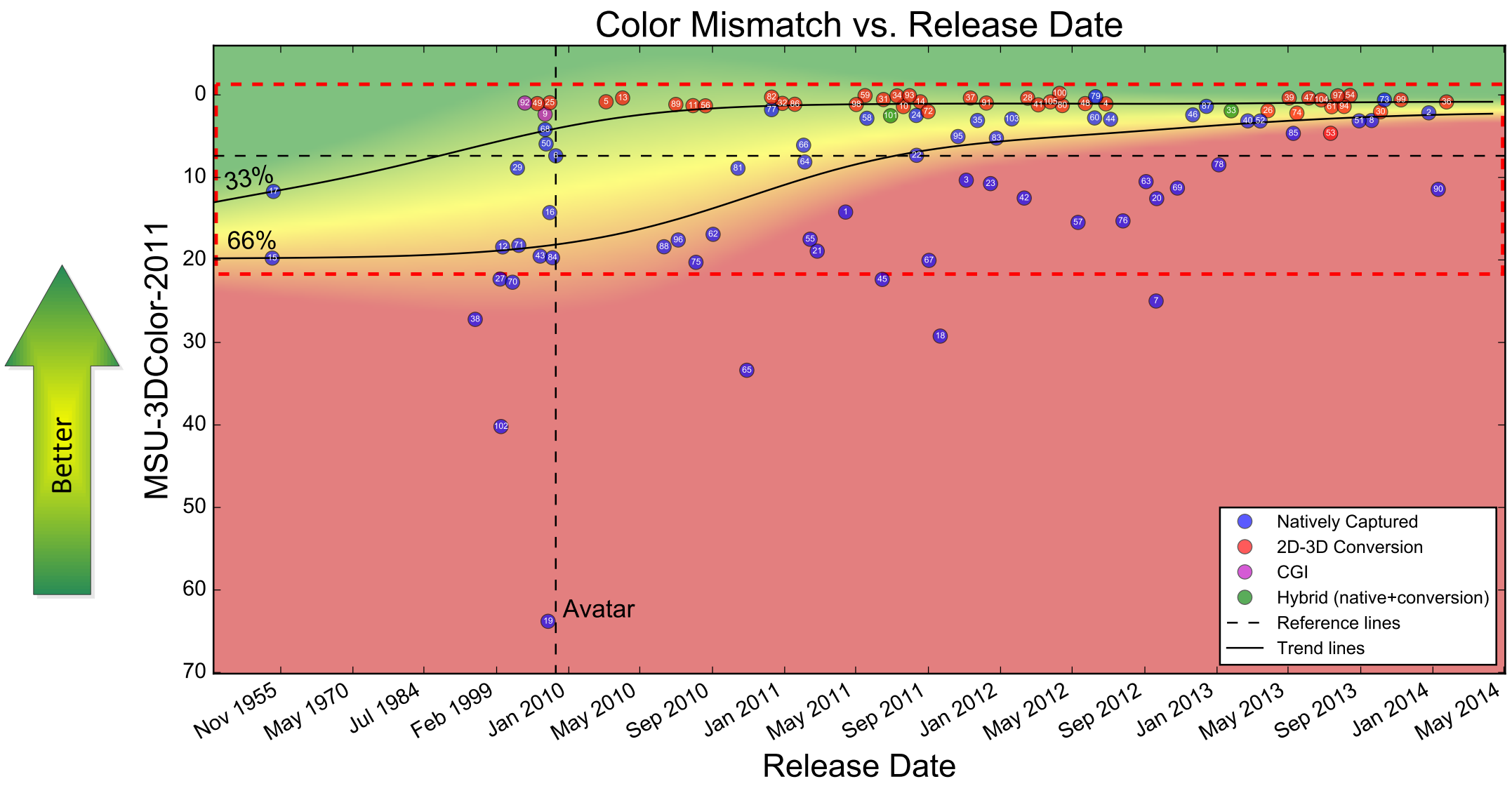


Figure 2.25: Diagram illustrating color mismatch metric value relative to movie release date

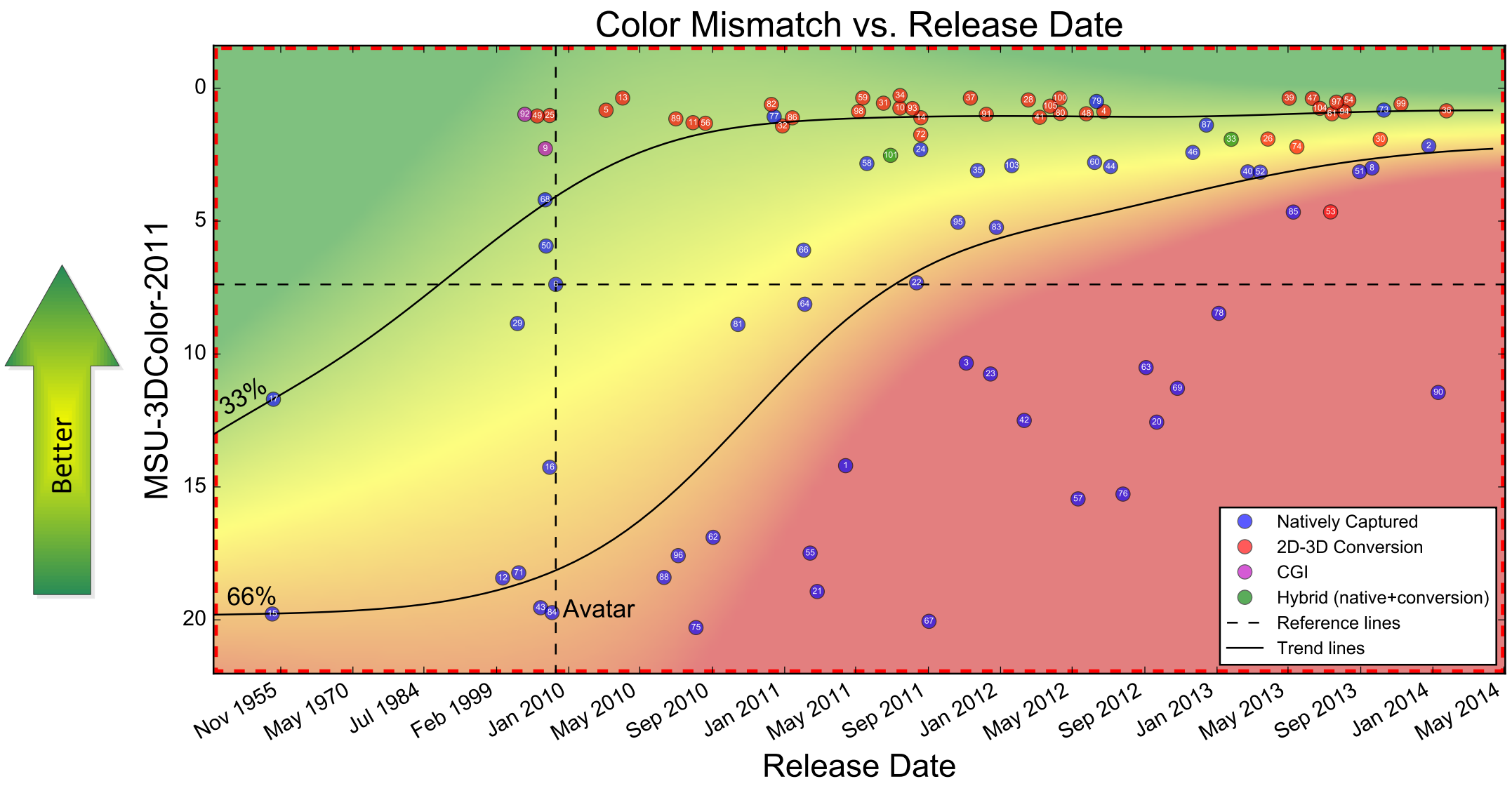


Figure 2.25a: Magnified fragment of the diagram in Figure 2.25

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

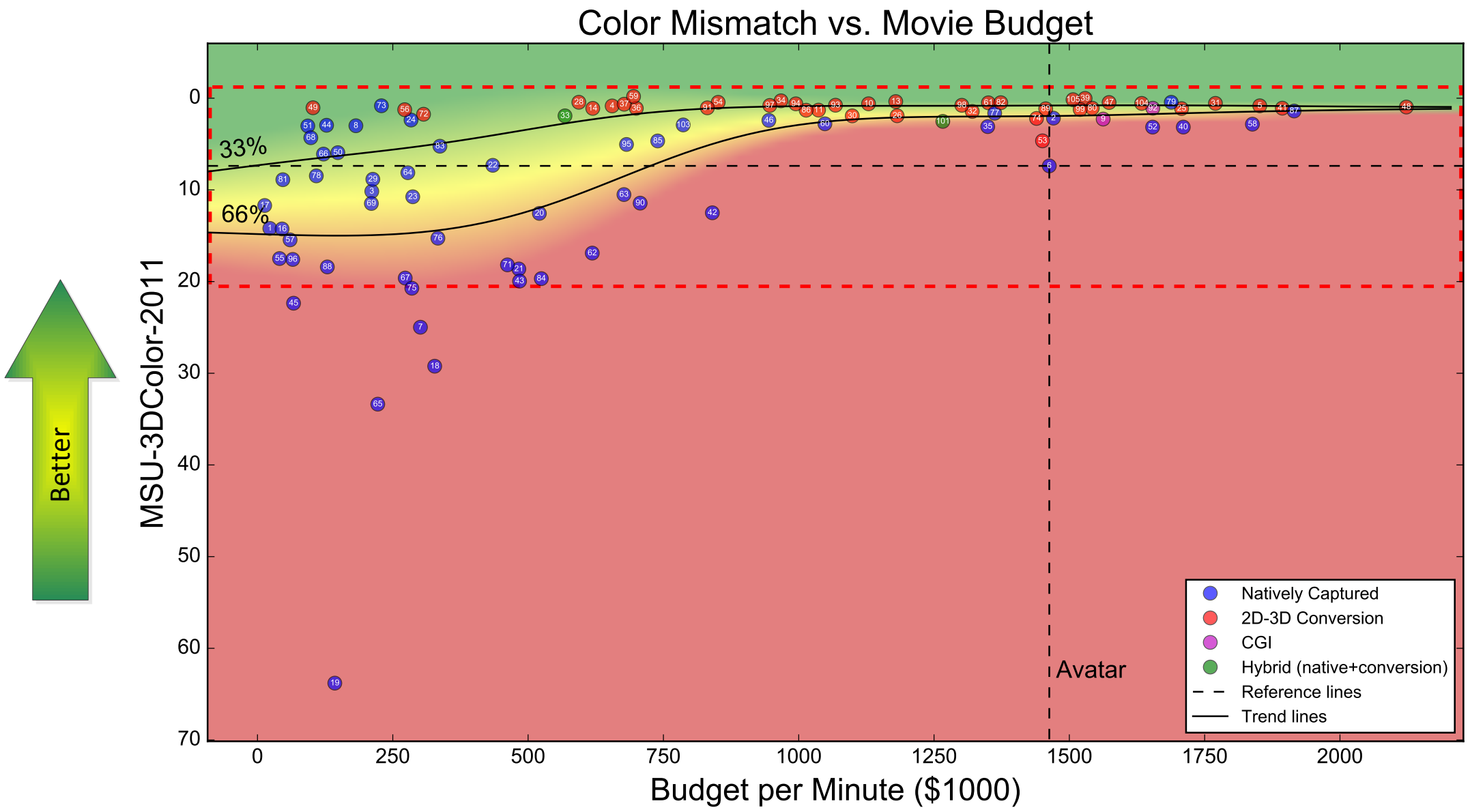


Figure 2.26: Diagram illustrating color mismatch metric value relative to movie budget (per minute)

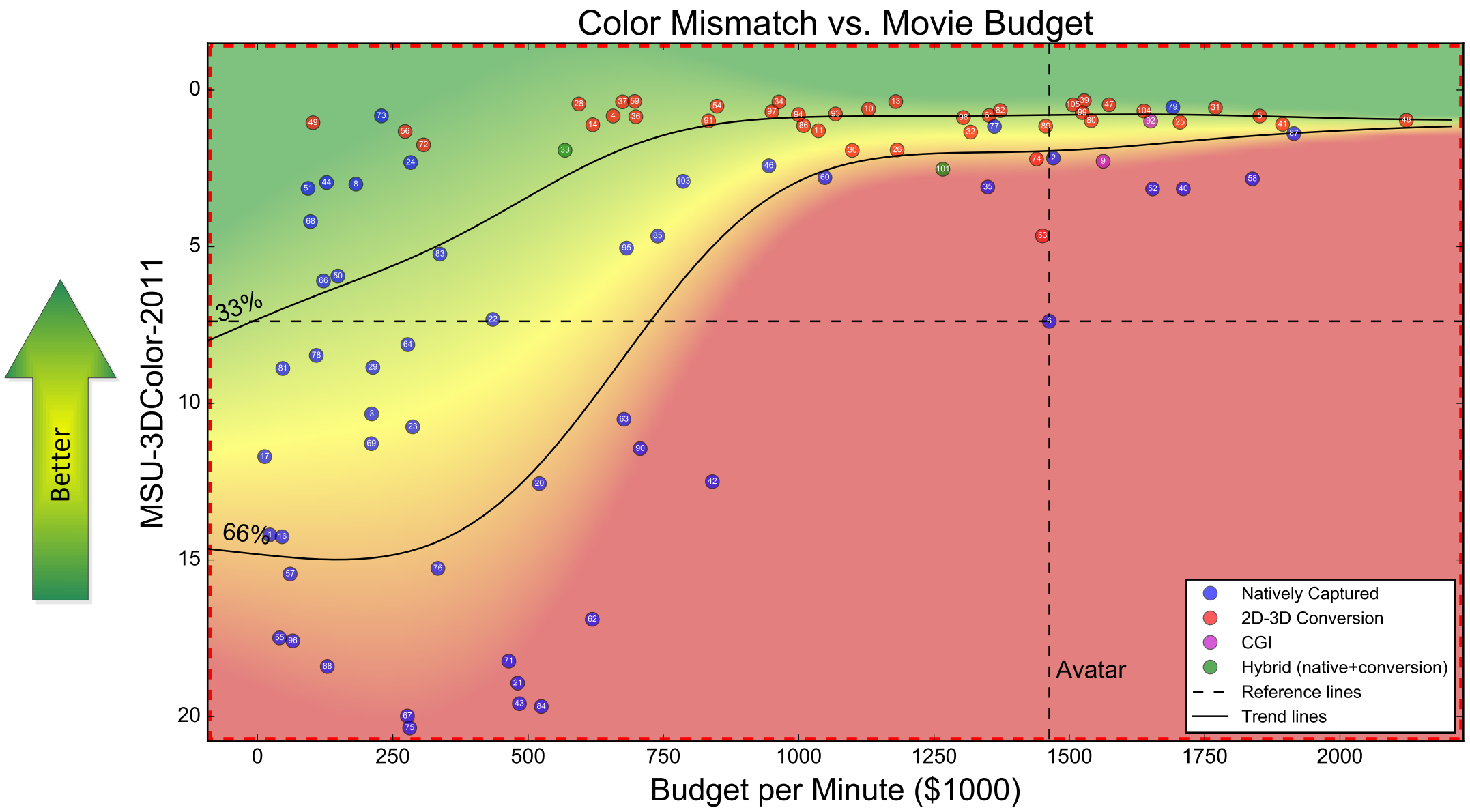


Figure 2.26a: Magnified fragment of the diagram in Figure 2.26

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

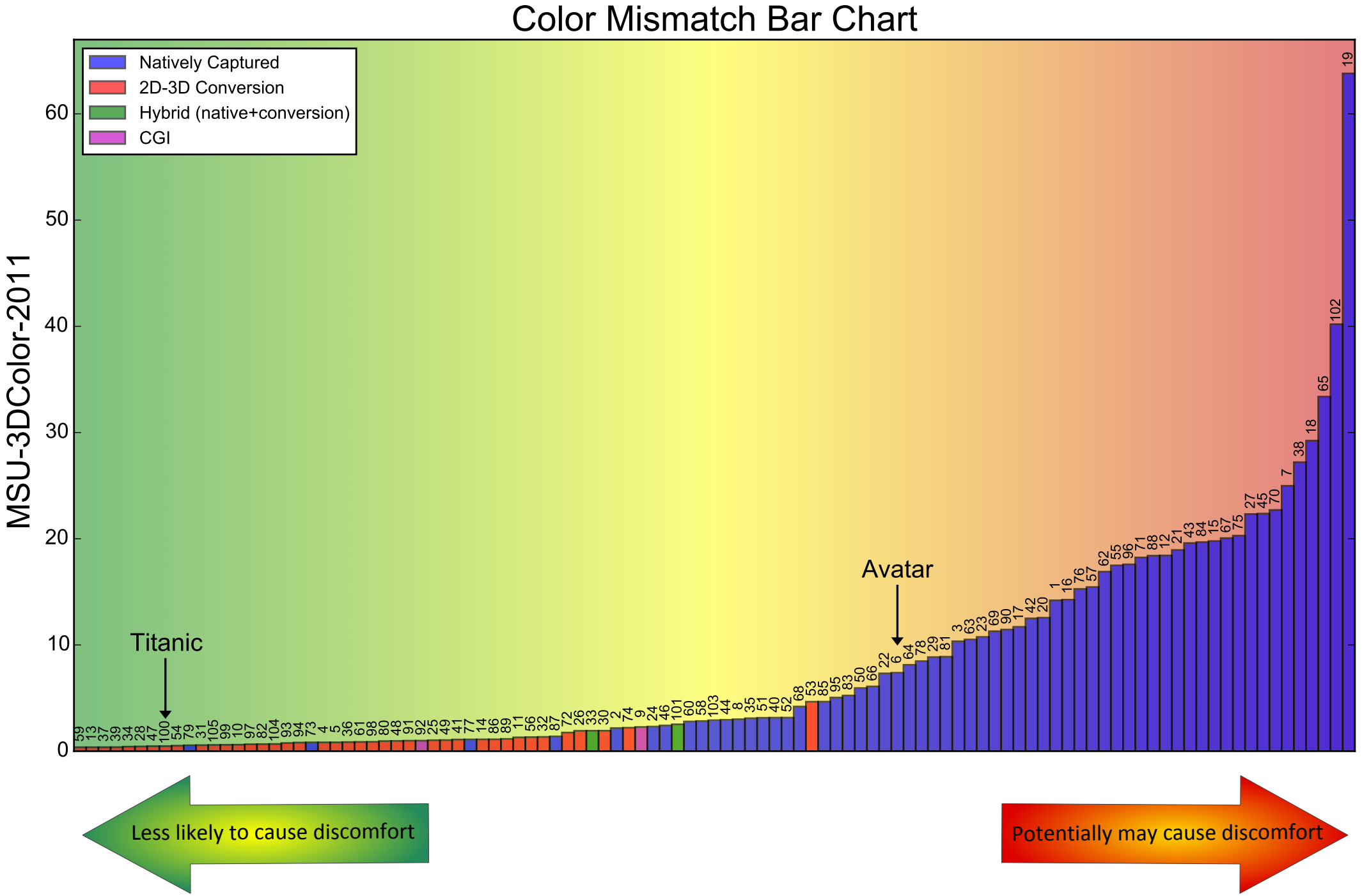


Figure 2.27: Bar chart with movies sorted by average color mismatch metric value in ascending order

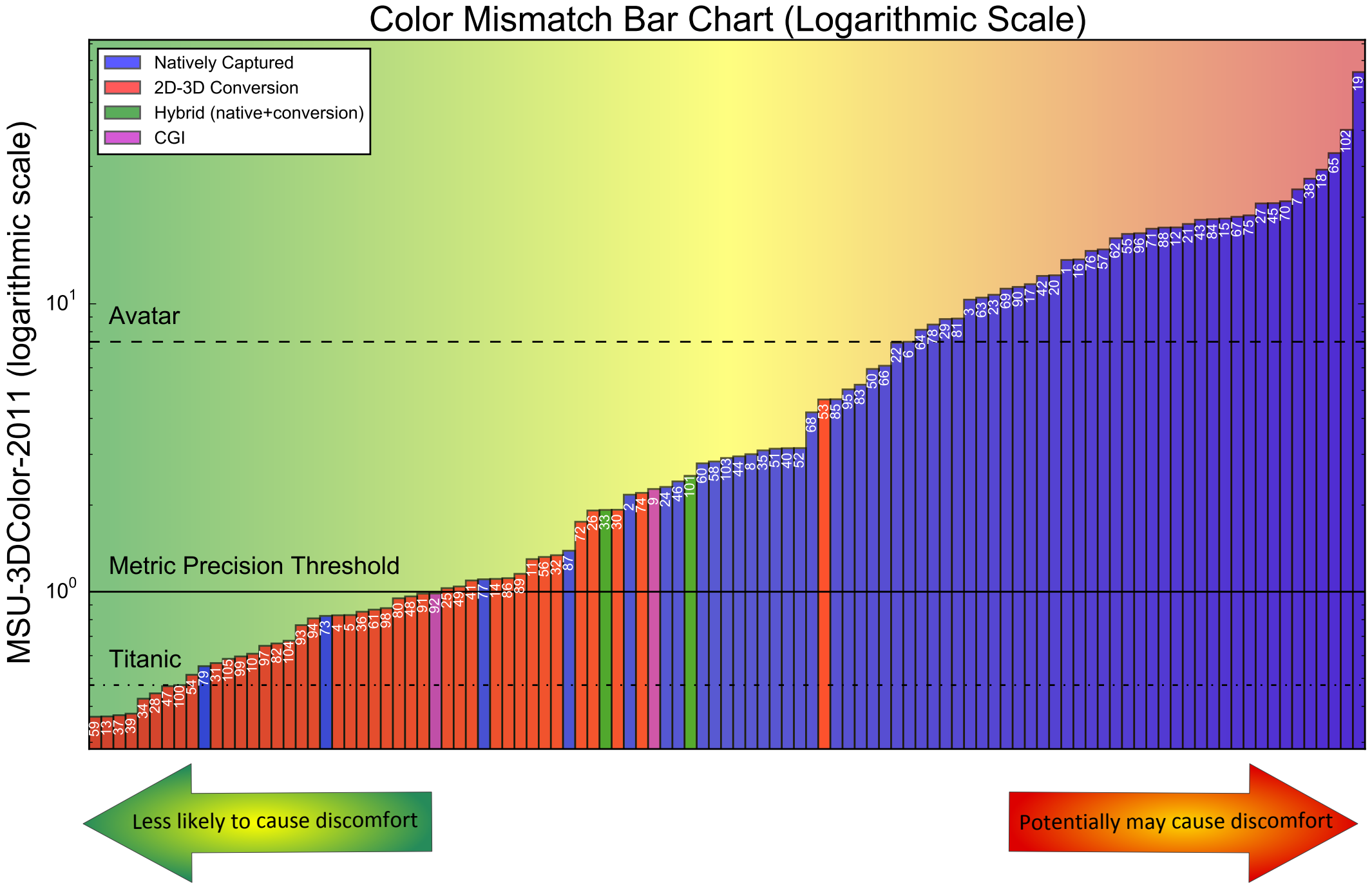


Figure 2.27a: Bar chart with movies sorted by average color mismatch metric value in ascending order (logarithmic scale)

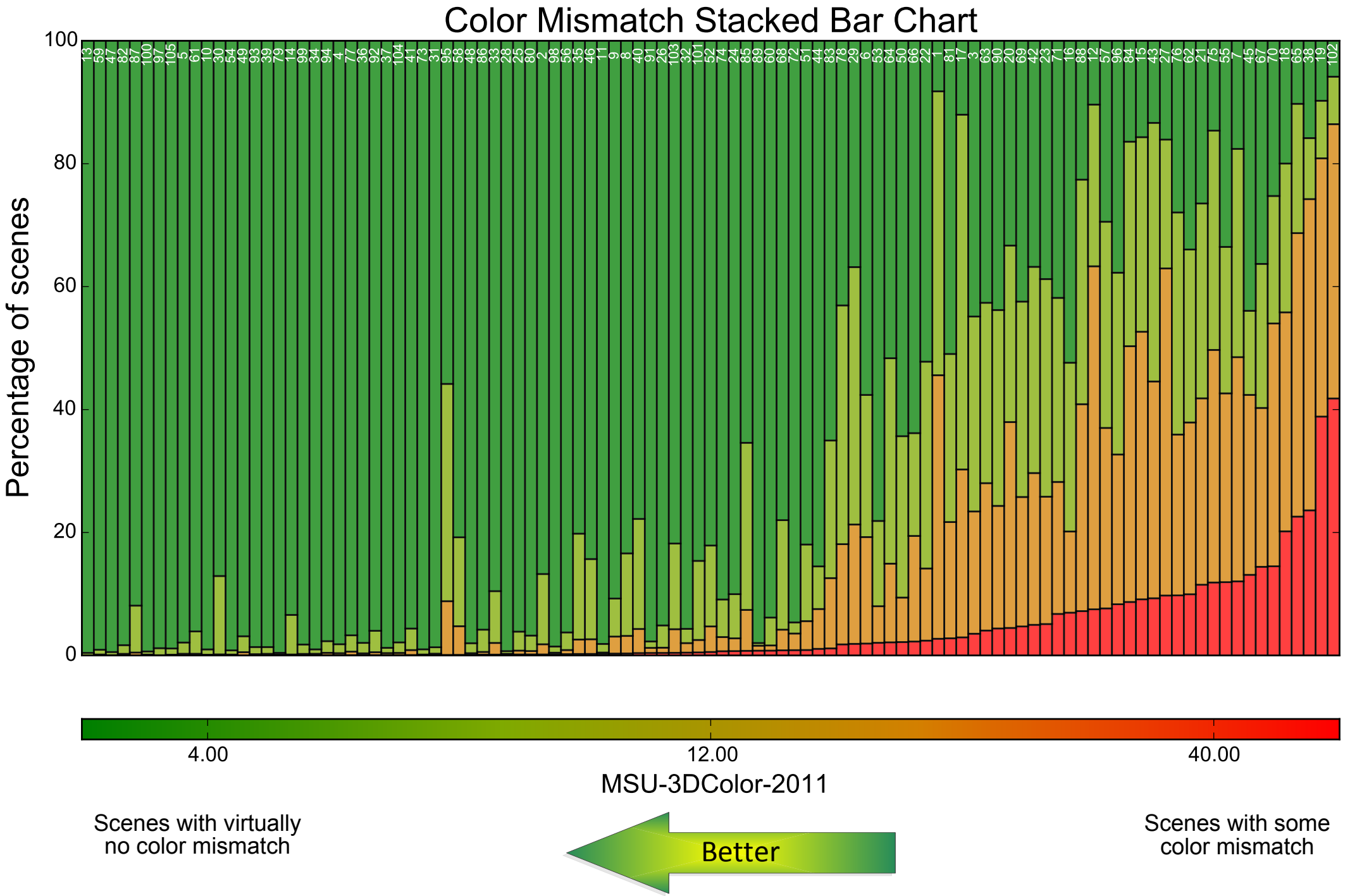


Figure 2.28: Stacked bar chart with movies sorted by the amount of low-technical-quality scenes

2.6 Sharpness Mismatch

Figure 2.29: Schematic illustration of a stereo pair with sharpness mismatch

As with previous types of artifacts, we provide average sharpness-mismatch values for our selected films in four diagrams: two scatterplots (one relative to movie release date and one relative to movie budget), one bar chart and one stacked bar chart. Sharpness-mismatch values are dimensionless; we obtained them using the MSU-3Dsharpness-2012 metric. Each one represents the difference in sharpness between two views of a stereoscopic frame. The value indicates sharpness-mismatch noticeability, which depends on the size of the region containing the sharpness mismatch and on the mismatch strength. We provide a more thorough description of this metric in [9].

A particular case of sharpness mismatch commonly arises in converted S3D movies: edge-sharpness mismatch (see [13] for more details). Owing to imperfections during postproduction, some sharpness mismatch—beyond common edge-sharpness mismatch—can still occur during 2D-to-3D conversion. Examples appear in [3,5]. Our general-purpose sharpness-mismatch metric, however, lacks sufficient accuracy to properly capture the subtle edge-sharpness-mismatch issues that prevail in converted S3D movies. Thus, the diagrams in this section only include natively captured 3D films.

See Sharpness Mismatch Examples in Our Previous Reports (889 pages and 1139 figures in reports dedicated to native S3D, 689 pages and 740 figures in reports dedicated to 2D-3D conversion)
A lot of sharpness mismatch examples in captured movies (137 figures in total) and per-frame analysis charts can be found here:

- MSU VQMT3D Report 1 (March 2013, 246 pages, 295 figures) [1]
- MSU VQMT3D Report 2 (May 2013, 342 pages, 442 figures) [2]
- MSU VQMT3D Report 4 (October 2013, 301 pages, 402 figures) [4]

A lot of examples of edge-sharpness mismatch (155 figures in total) and several examples of general-case sharpness mismatch (22 figures in total) in 2D-3D conversion can be found here:

- MSU VQMT3D Report 3 (August 2013, 305 pages, 336 figures) [3]
- MSU VQMT3D Report 5 (April 2014, 384 pages, 404 figures) [5]

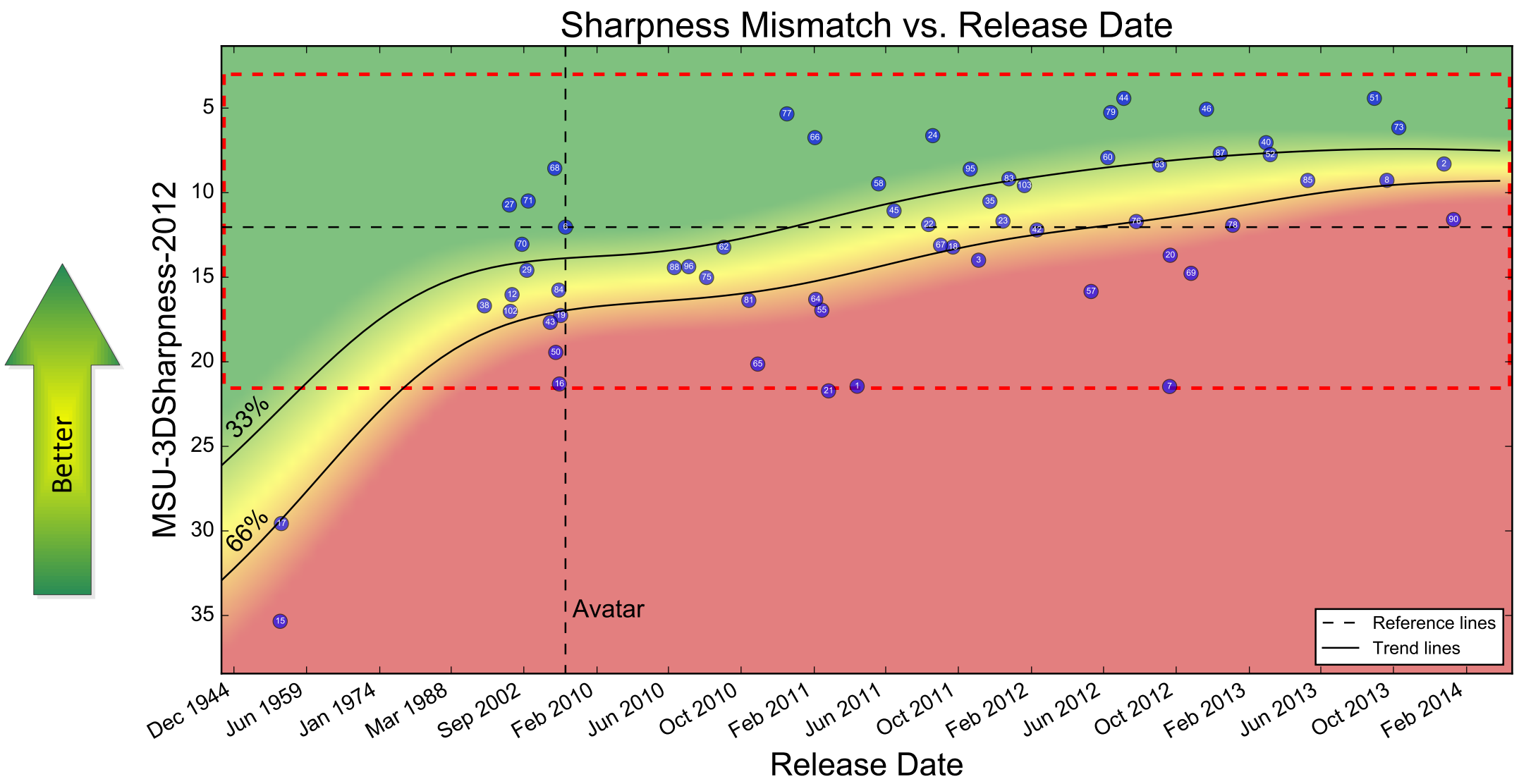


Figure 2.30: Diagram illustrating sharpness mismatch metric value relative to release date

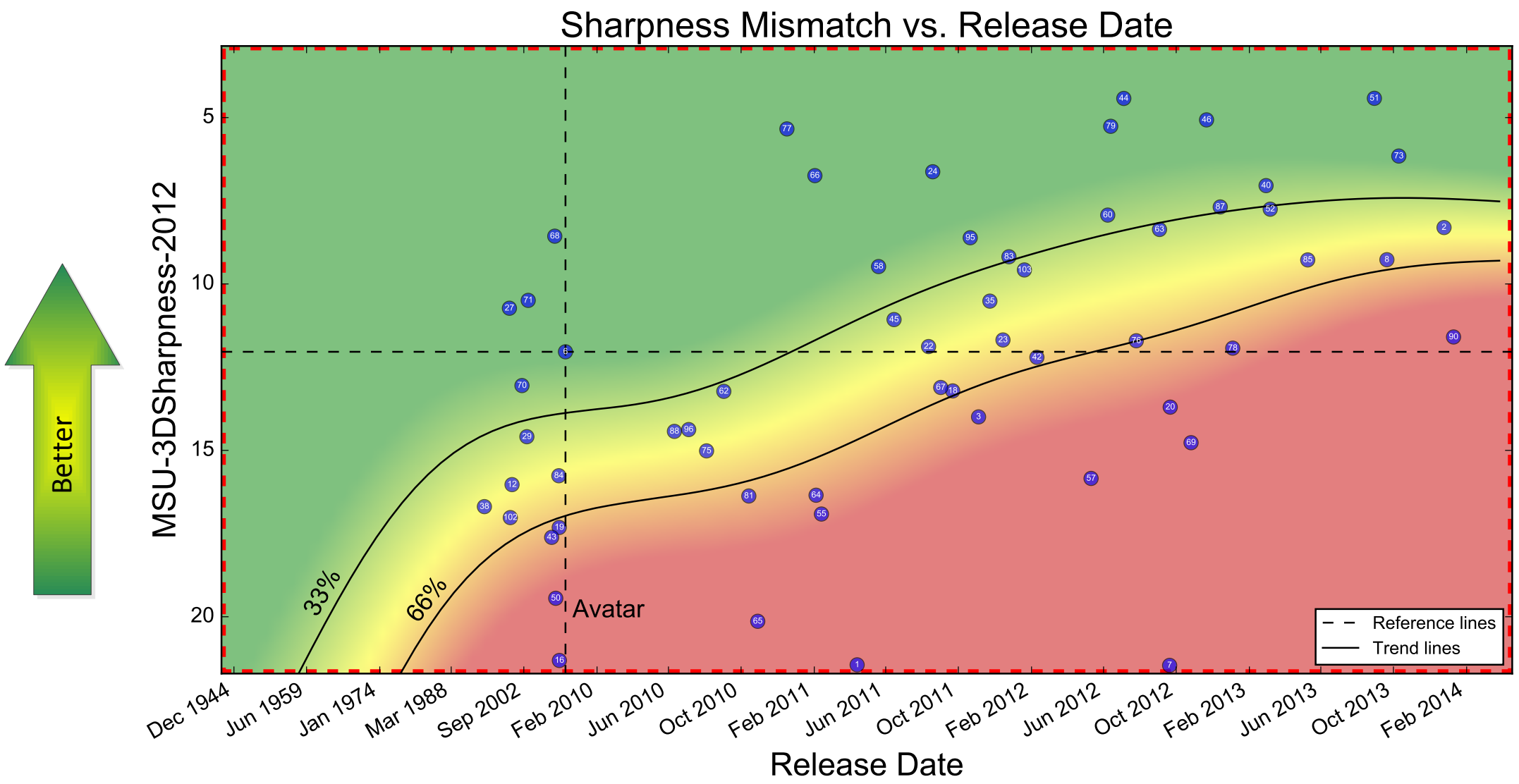


Figure 2.30a: Magnified fragment of the diagram in Figure 2.30

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

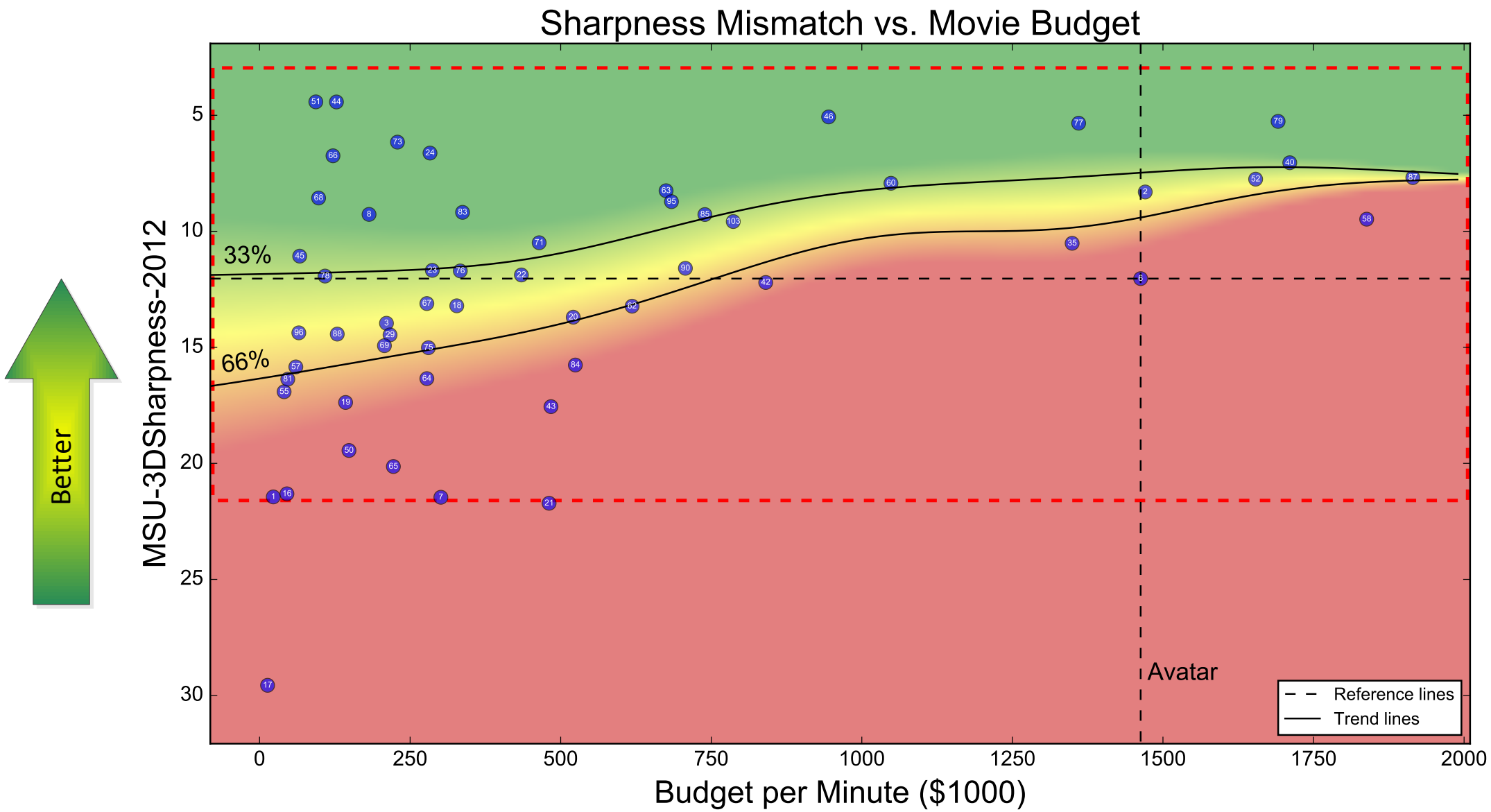


Figure 2.31: Diagram illustrating sharpness mismatch metric value relative to movie budget (per minute)

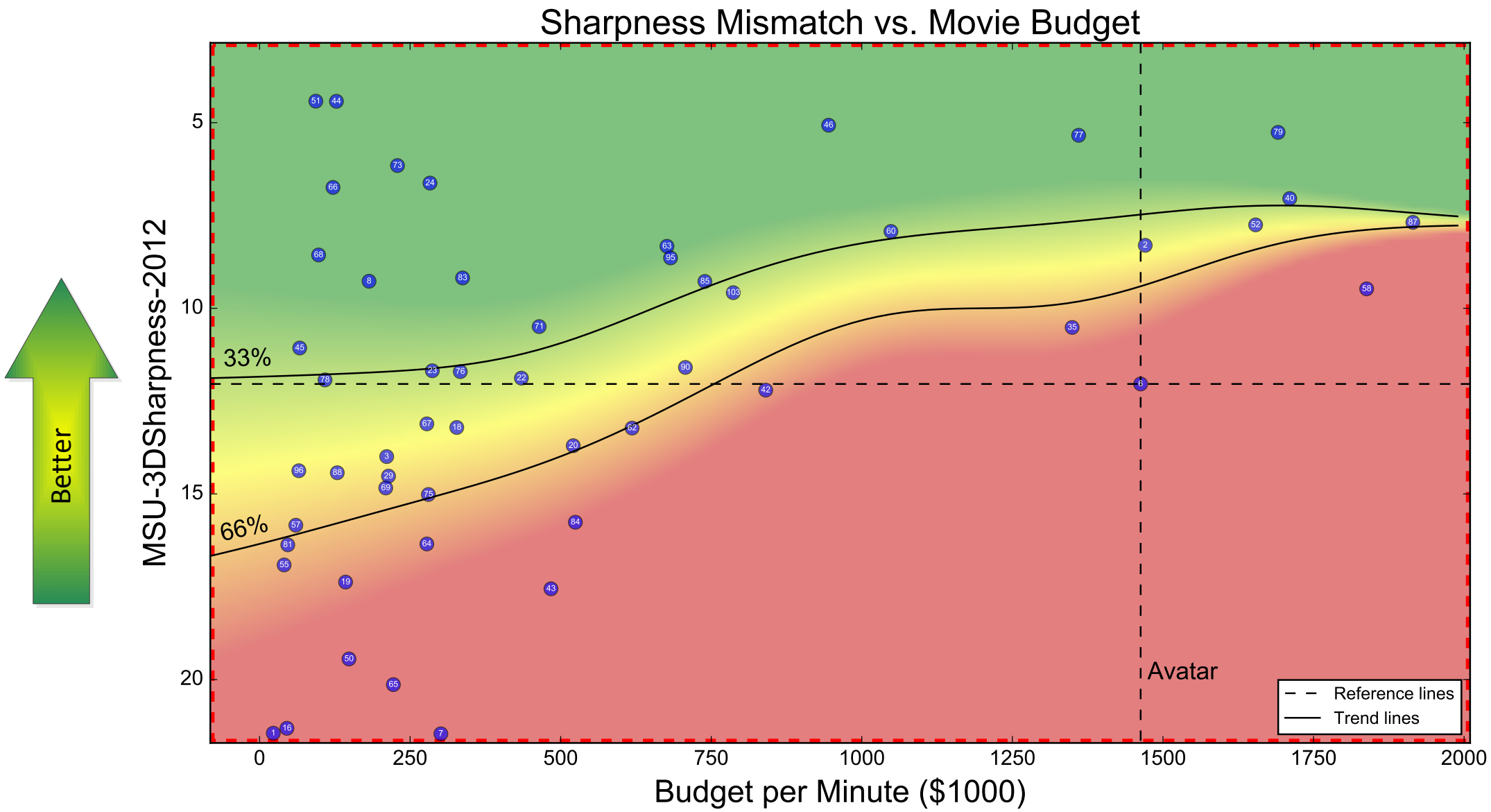


Figure 2.31a: Magnified fragment of the diagram in Figure 2.31

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

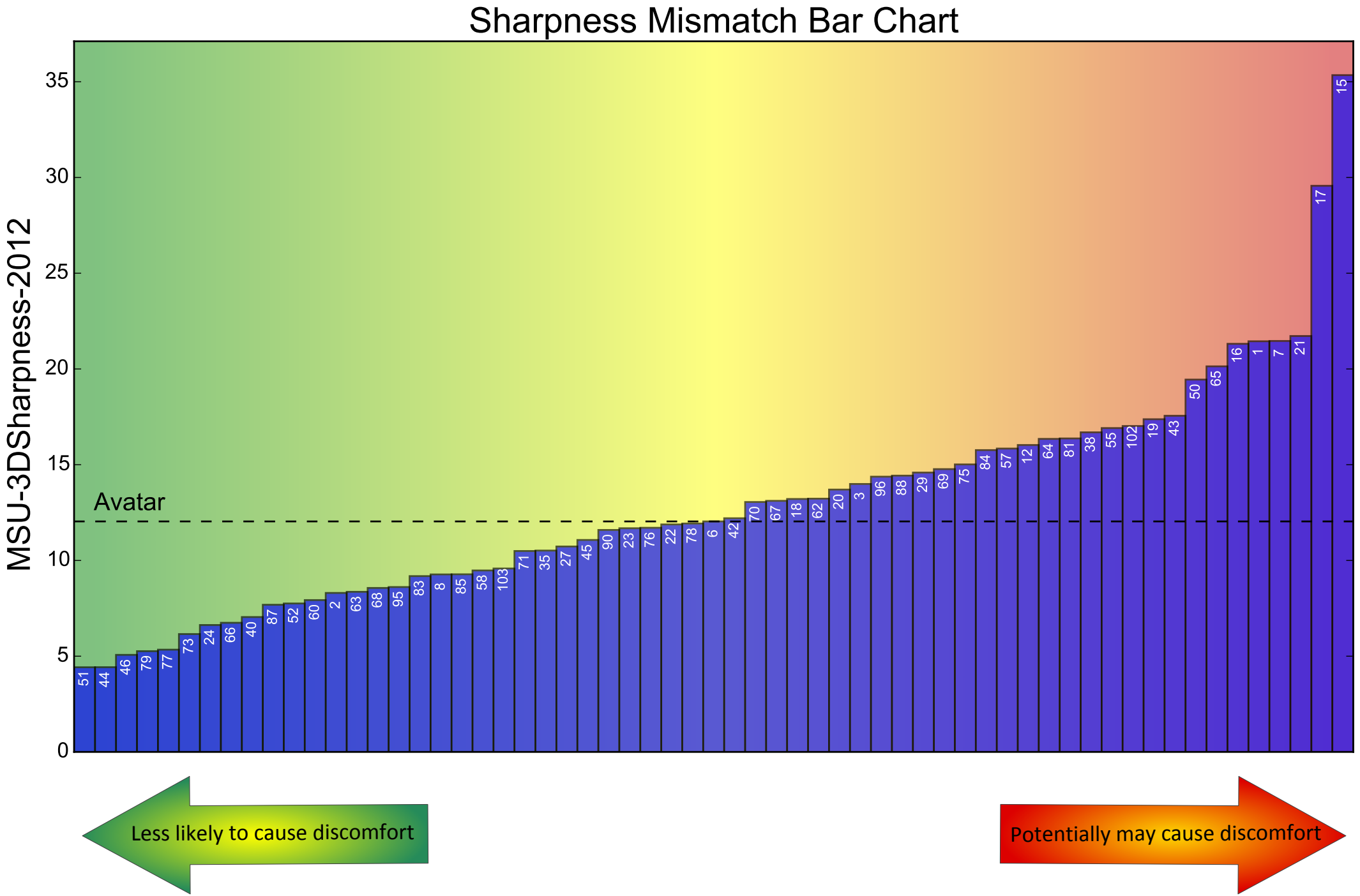


Figure 2.32: Bar chart with movies sorted by average sharpness mismatch metric value in ascending order

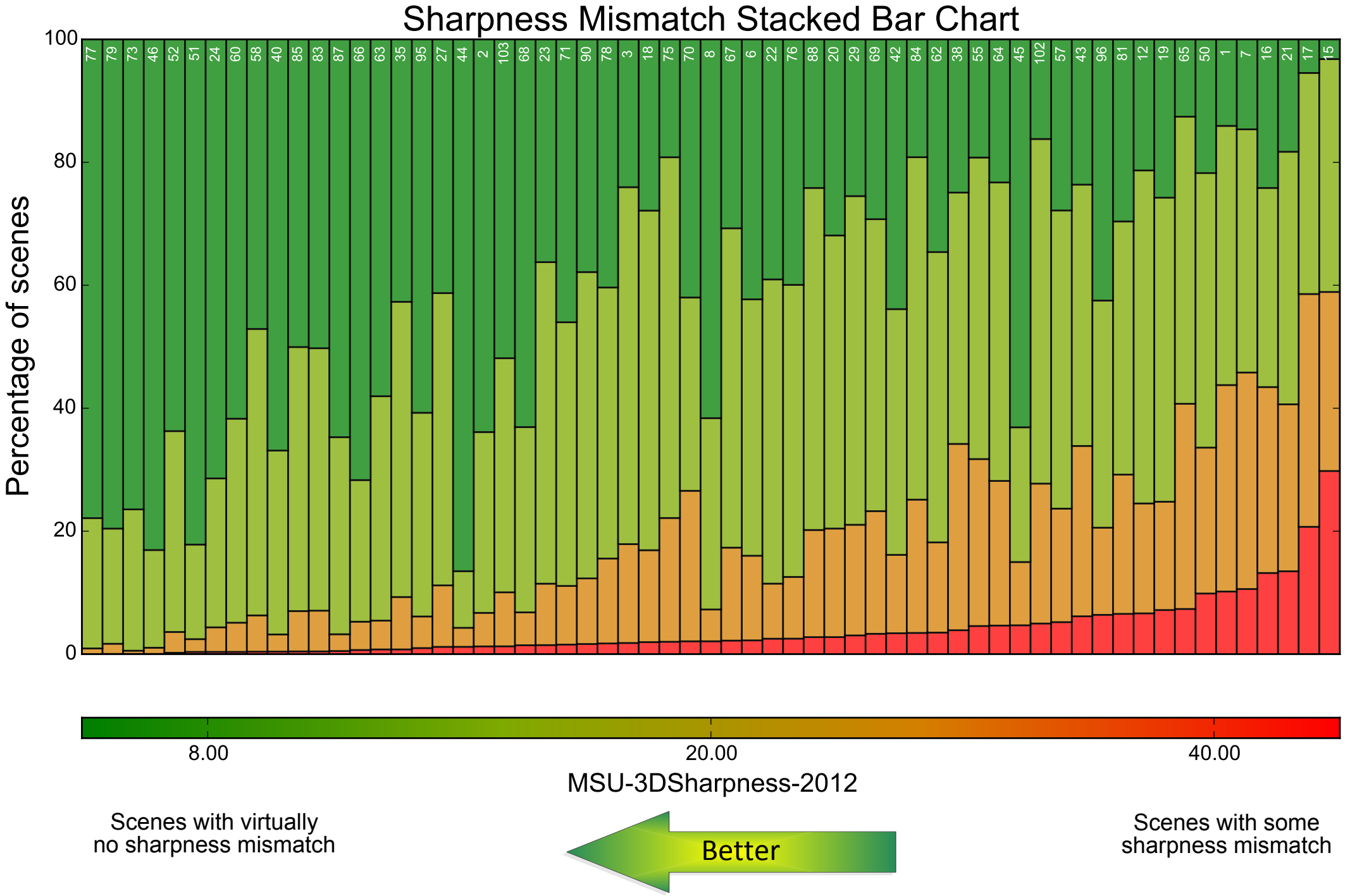


Figure 2.33: Stacked bar chart with movies sorted by the amount of low-technical-quality scenes

2.7 Stereo Window Violation

Figure 2.34: Schematic illustration of a stereo pair with stereo window violation

Our stereo-window-violation analysis comprises two metrics: stereo-window-placement comfort measured by MSU-StereoWindowComfort-2014 and quality of stereo-window-violation handling measured by MSU-StereoViolationHandling-2014. Both are dimensionless. The first one aims to assess viewing comfort. It takes into account both average stereo-window-violation noticeability (which depends on the size and sharpness of the edge-violating object) and average depth distribution throughout the movie (we consider an imbalanced parallax range shifted toward positive values to be less comfortable). Thus, the metric penalizes films that achieve low stereo-window-violation noticeability by placing nearly all the content behind the screen.

The second metric is more technical. We designed it to measure how well a given movie handles potentially problematic negative-parallax content. We consider both proper use of floating windows and placement of all negative-parallax content far from screen edges to be acceptable techniques. For both metrics this report provides three diagrams: one chart relative to movie-release date, one chart relative to movie budget and one bar chart with average metric values.

For more information on the negative effects of stereo-window violation and use of floating windows, consult our sixth and seventh VQMT3D reports [6, 7].

See Stereo Window Violation Examples in Our Previous Reports (748 pages and 803 figures in total)
Numerous stereo window violation examples both in captured and converted movies and per-frame stereo window analysis charts can be found here:

- MSU VQMT3D Report 6 (September 2014, 415 pages, 455 figures) [6]
- MSU VQMT3D Report 7 (October 2014, 333 pages, 348 figures) [7]

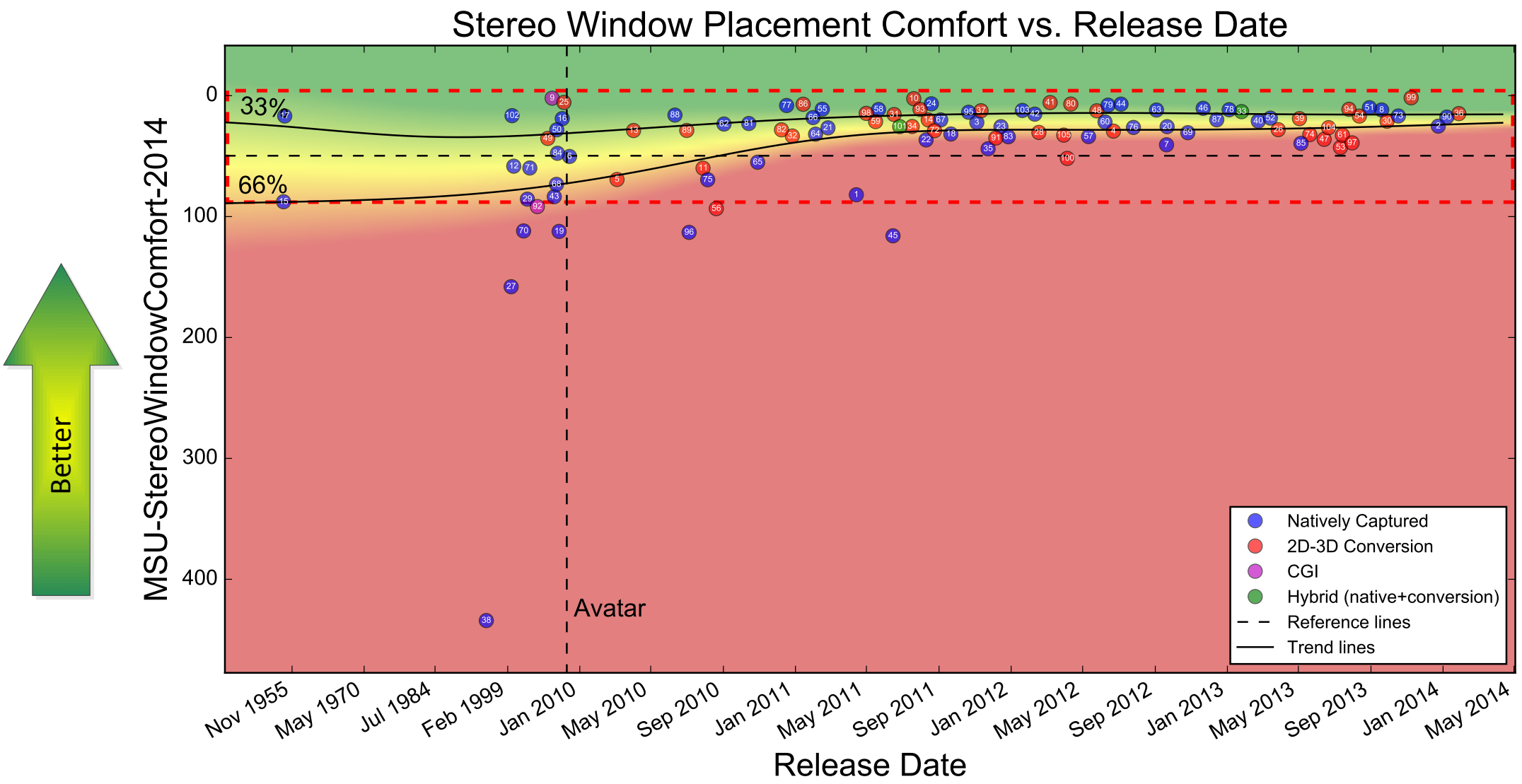


Figure 2.35: Diagram illustrating stereo window placement comfort metric value relative to movie release date

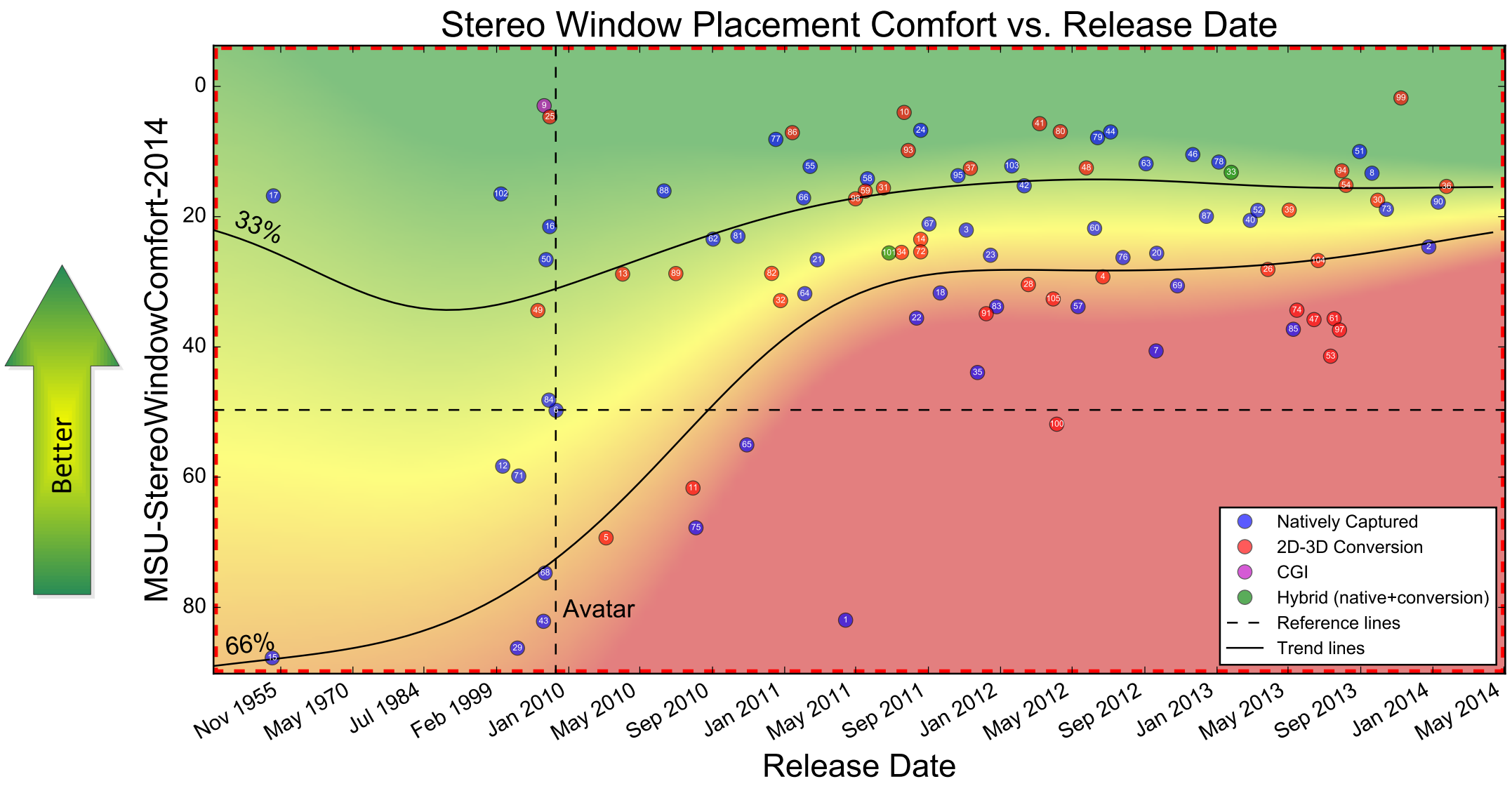


Figure 2.35a: Magnified fragment of the diagram in Figure 2.35

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

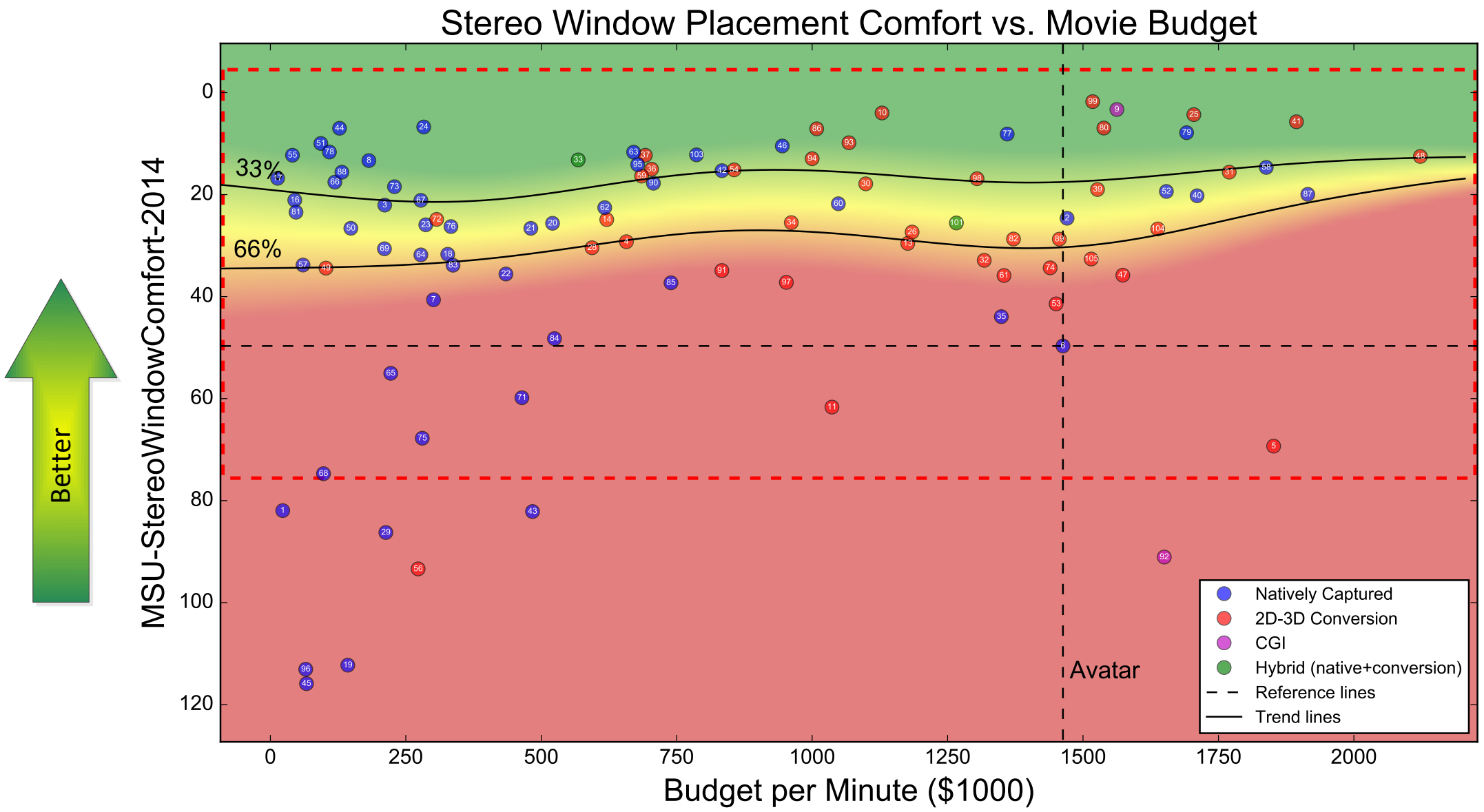


Figure 2.36: Diagram illustrating stereo window placement comfort metric value relative to movie budget (per minute)

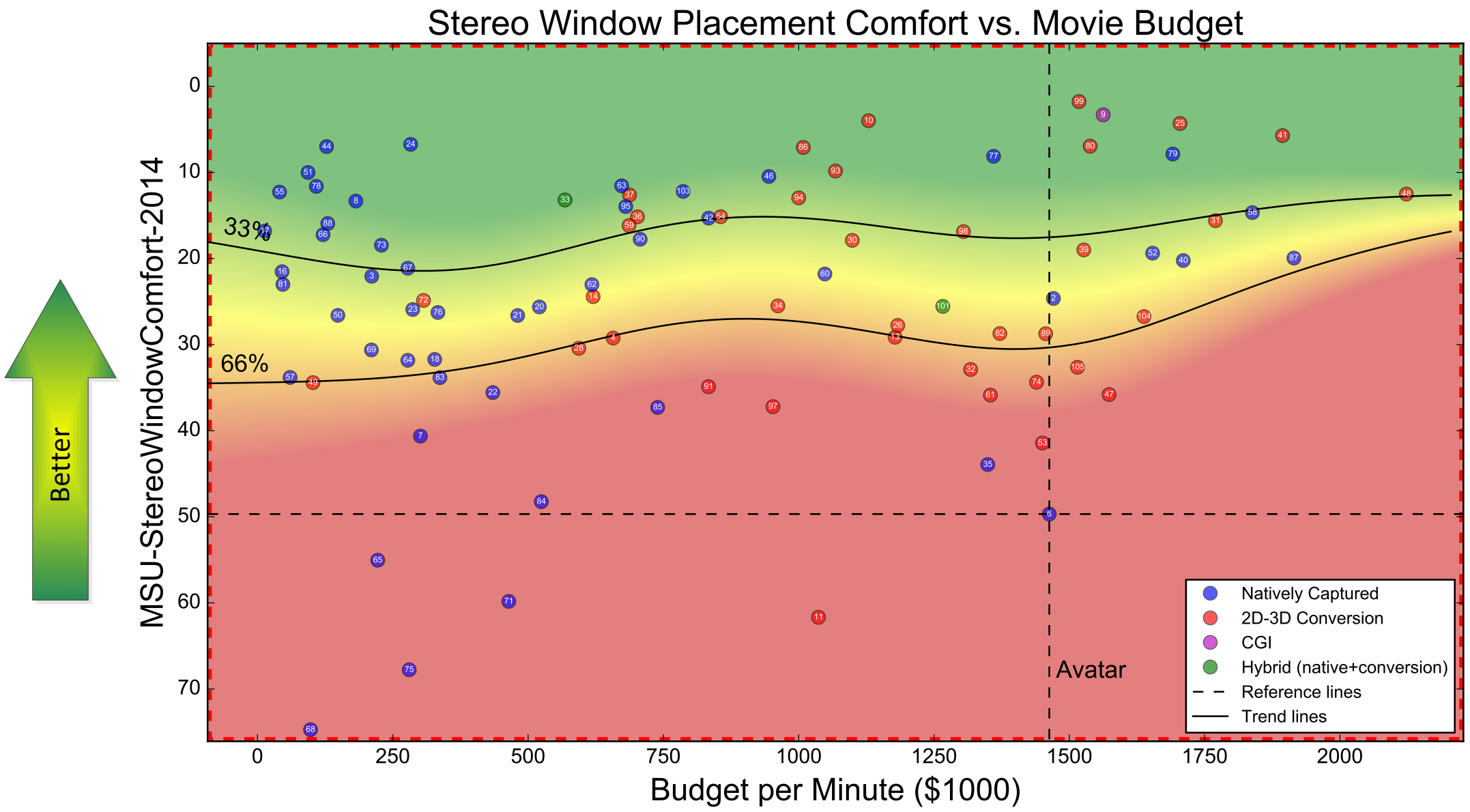


Figure 2.36a: Magnified fragment of the diagram in Figure 2.36

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

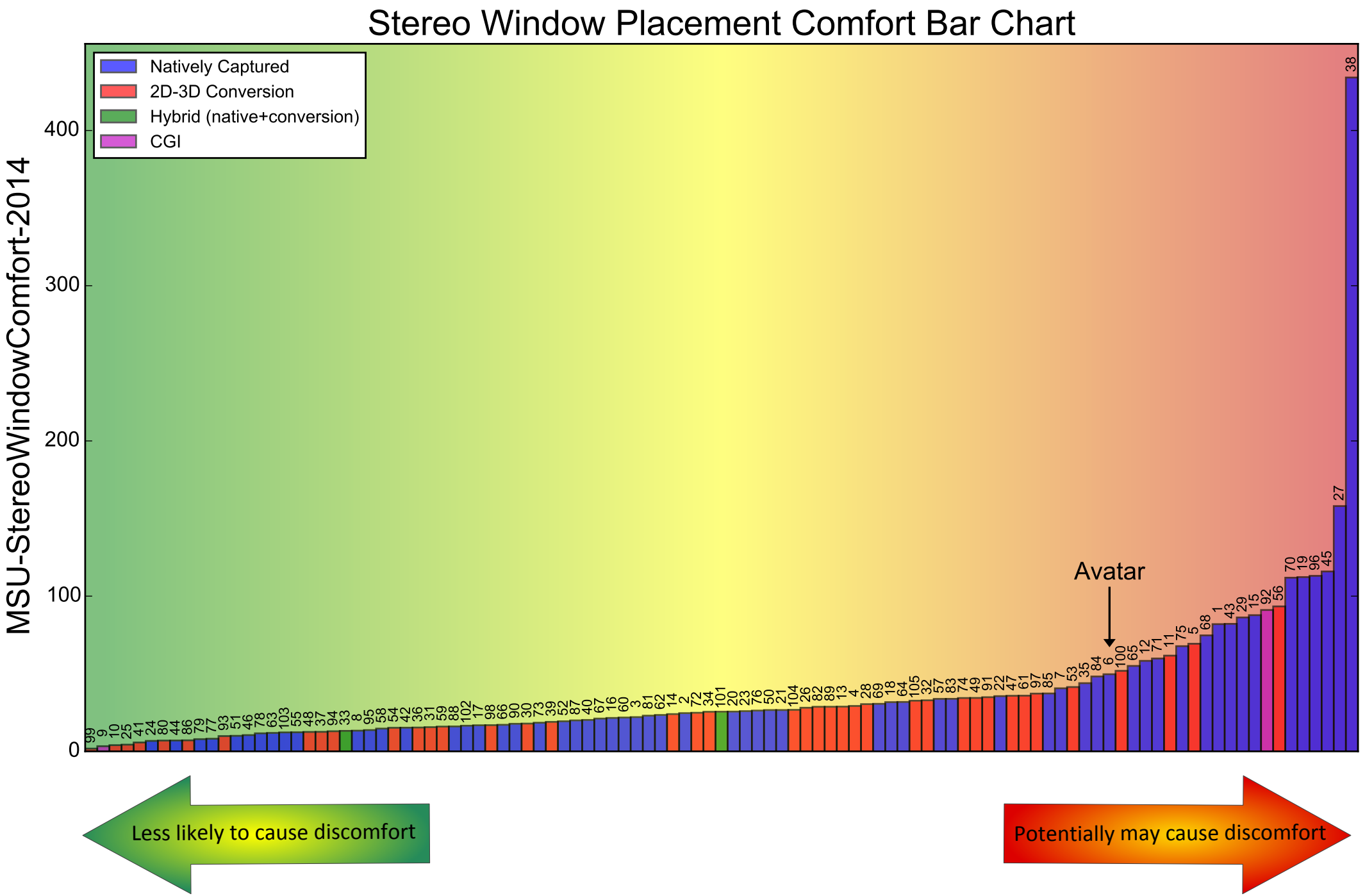


Figure 2.37: Bar chart with movies sorted by average stereo window placement comfort metric value in ascending order

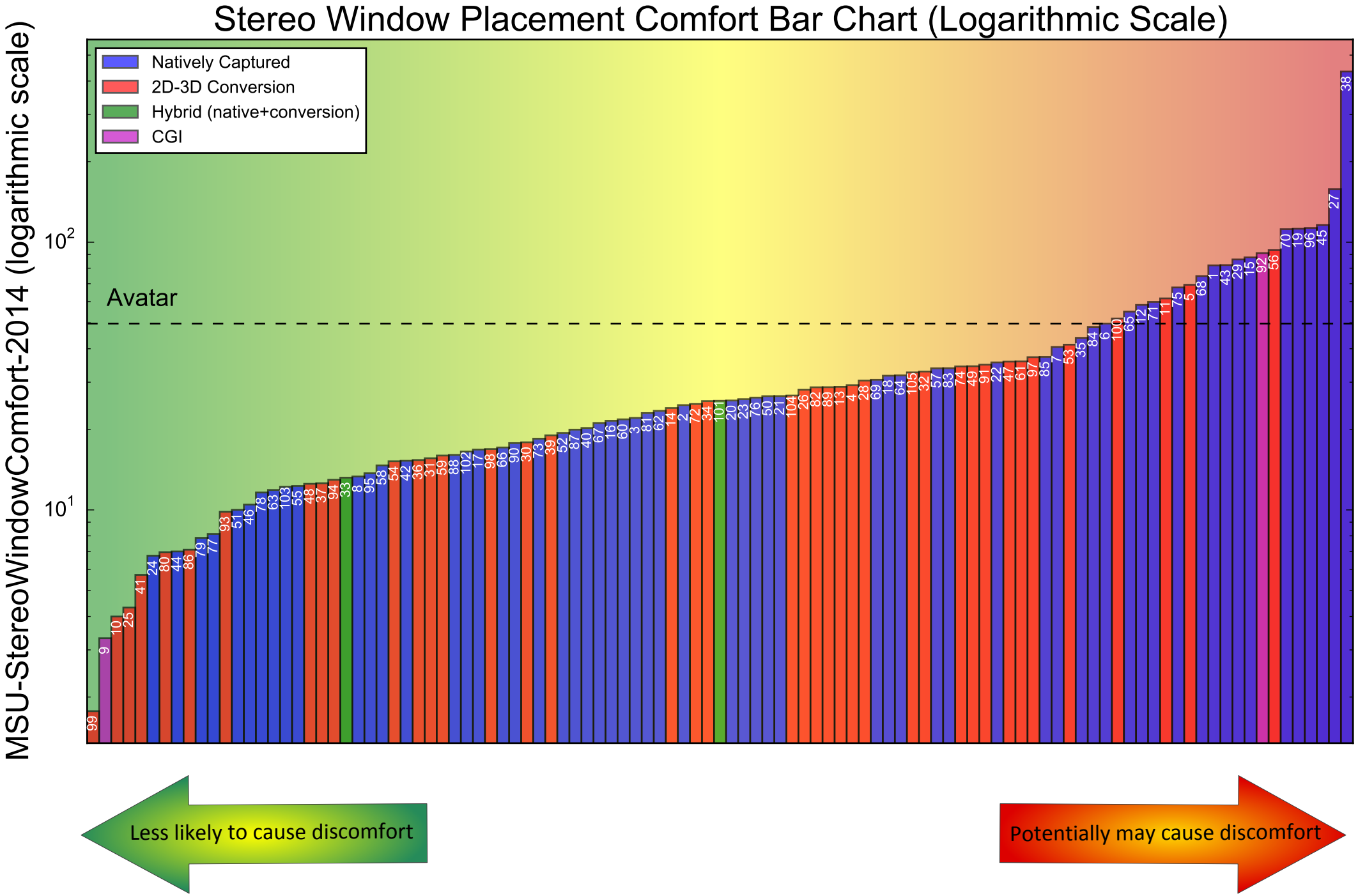


Figure 2.37a: Bar chart with movies sorted by average stereo window placement comfort metric value in ascending order (logarithmic scale)

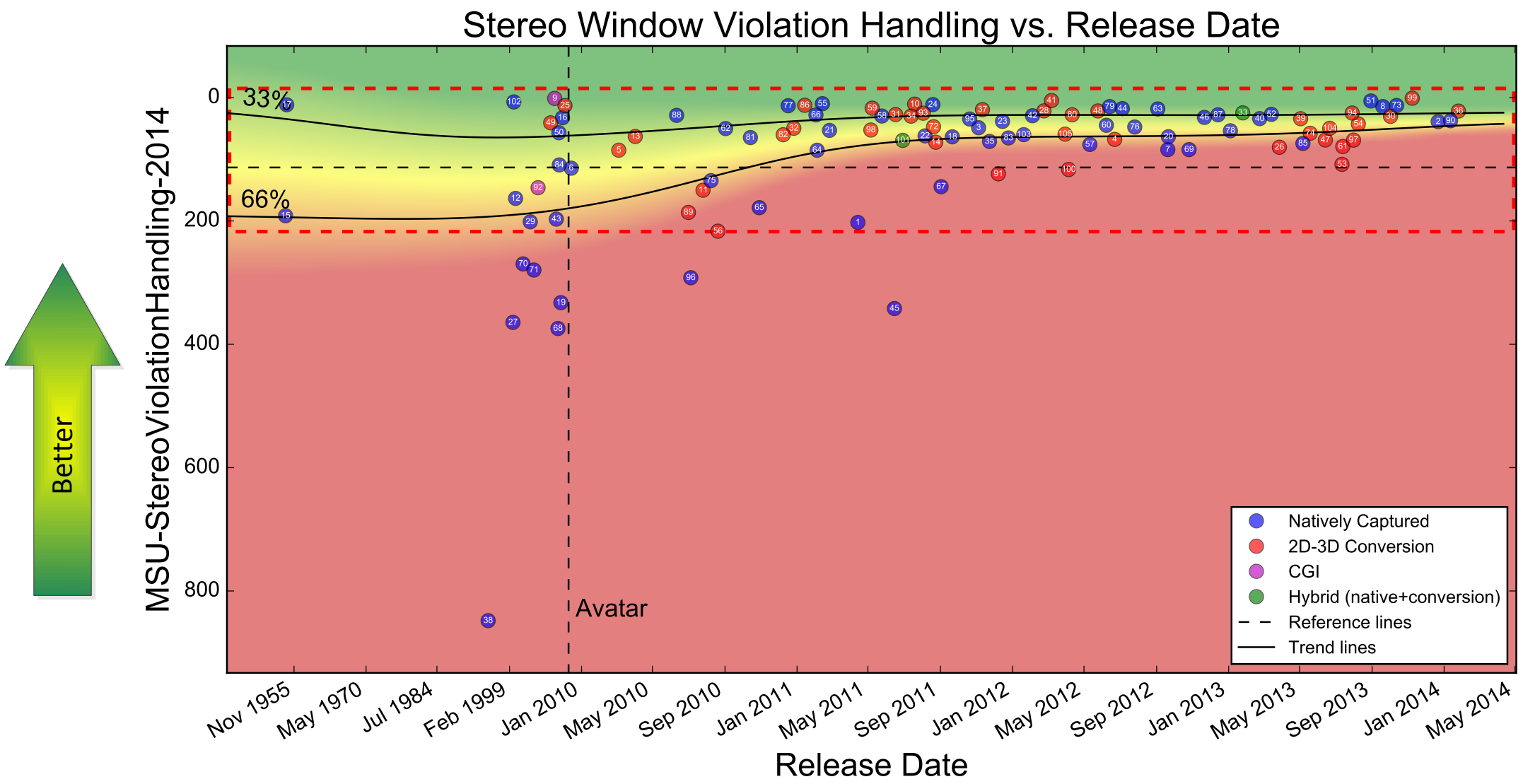


Figure 2.38: Diagram illustrating quality of stereo window violations handling metric value relative to movie release date

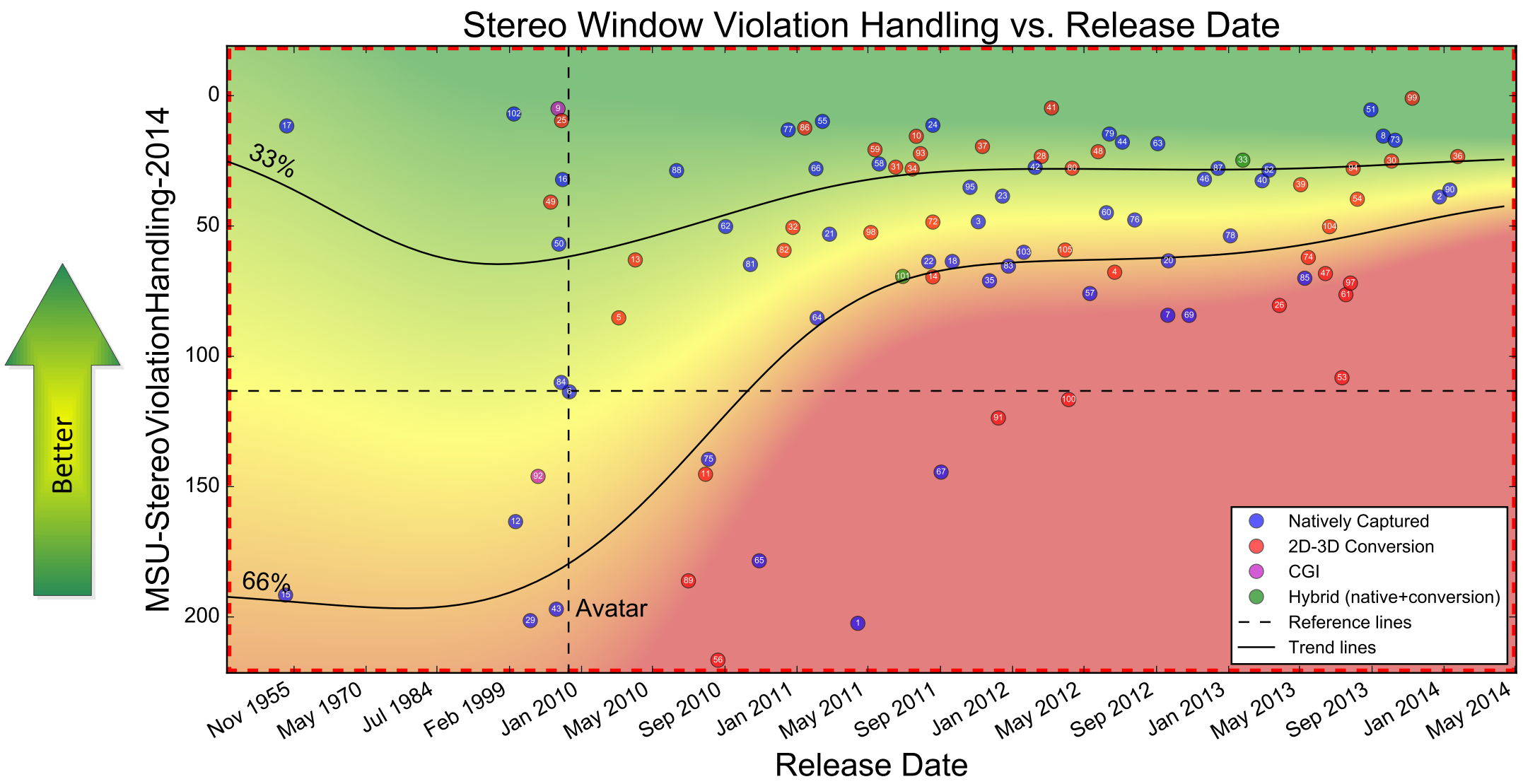


Figure 2.38a: Magnified fragment of the diagram in Figure 2.38

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

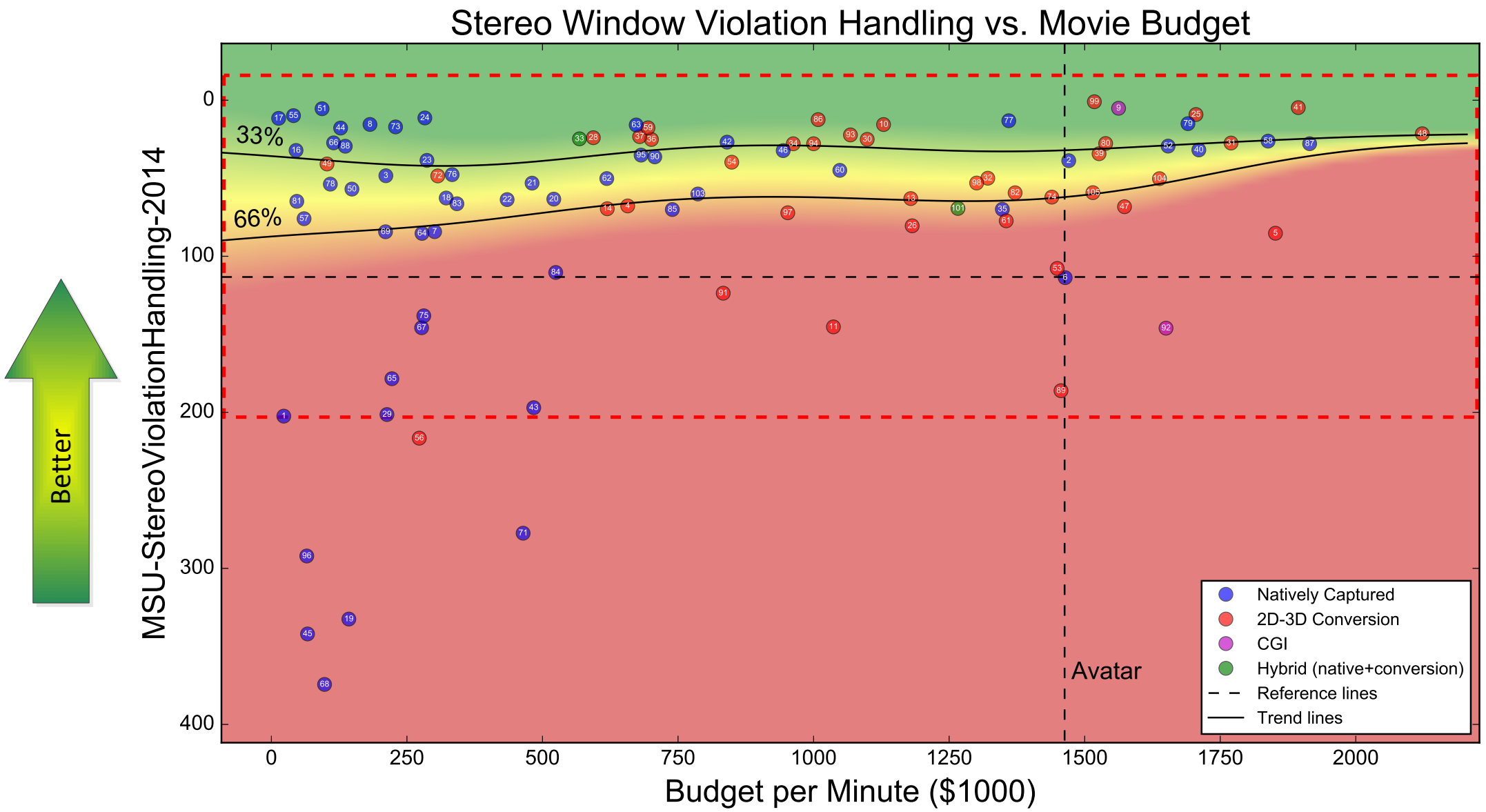


Figure 2.39: Diagram illustrating quality of stereo window violations handling metric value relative to movie budget (per minute)

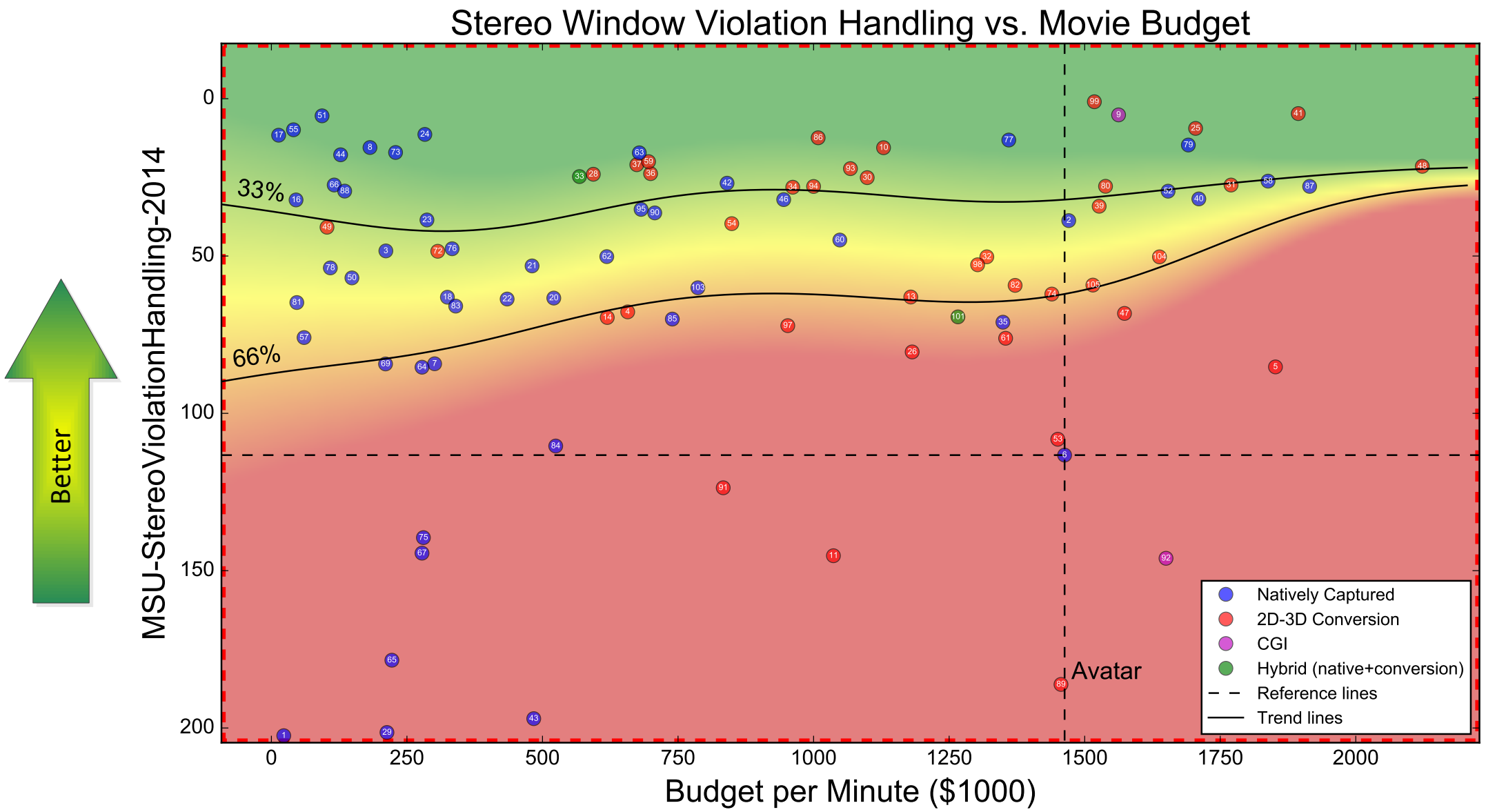


Figure 2.39a: Magnified fragment of the diagram in Figure 2.39

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

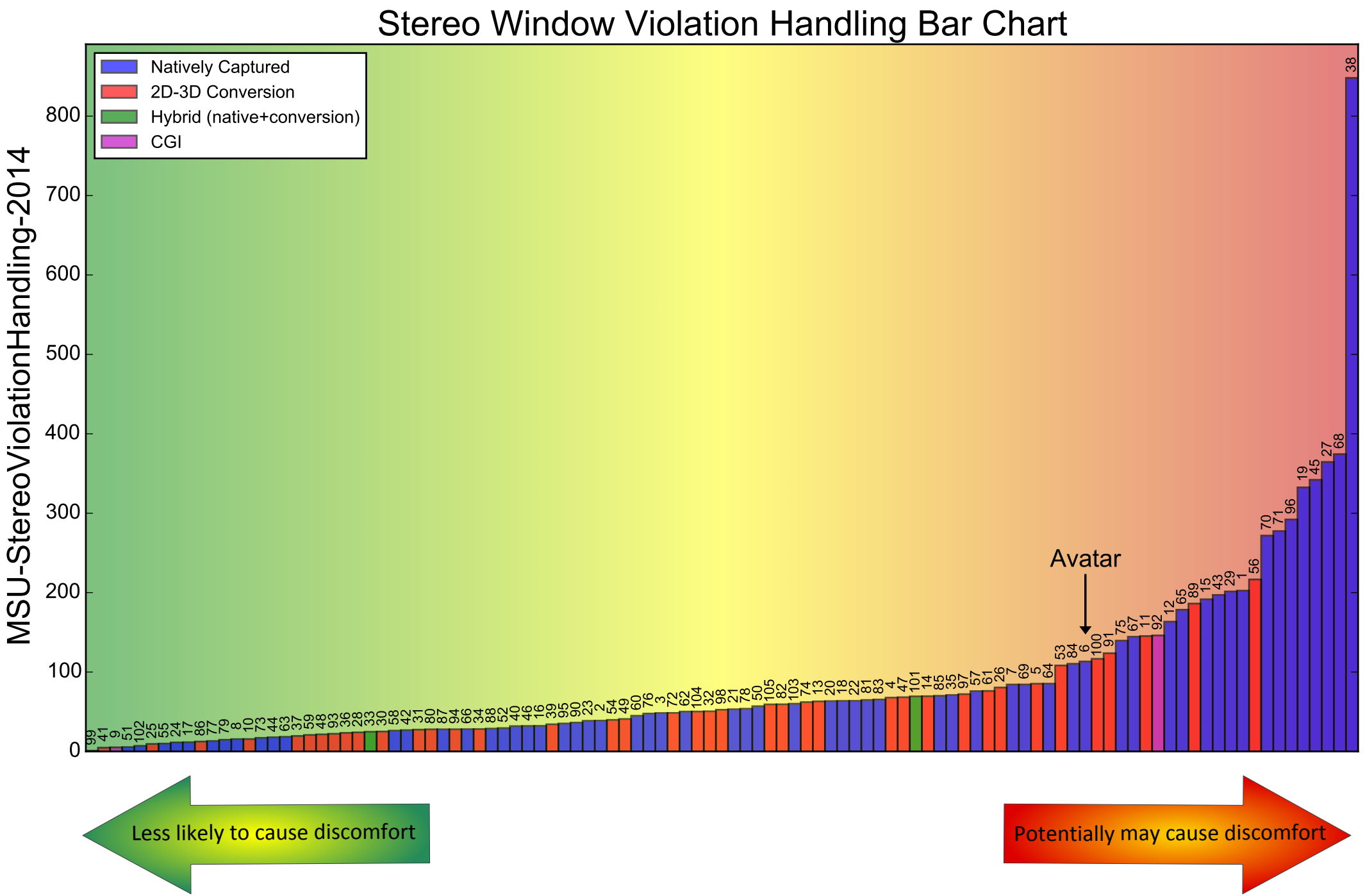


Figure 2.40: Bar chart with movies sorted by average stereo window violation handling metric value in ascending order

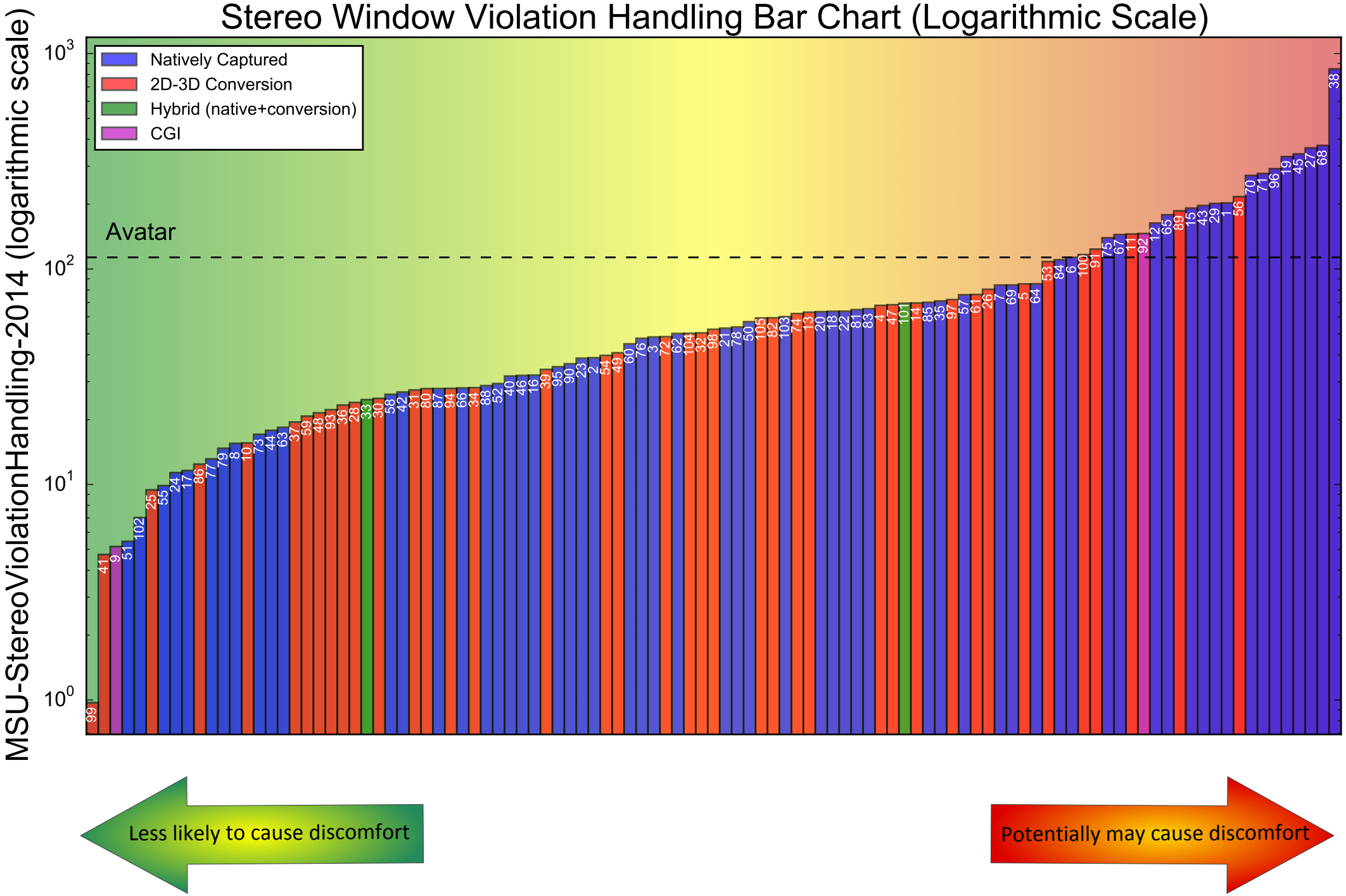


Figure 2.40a: Bar chart with movies sorted by average stereo window violation handling metric value in ascending order (logarithmic scale)

2.8 Temporal Shift

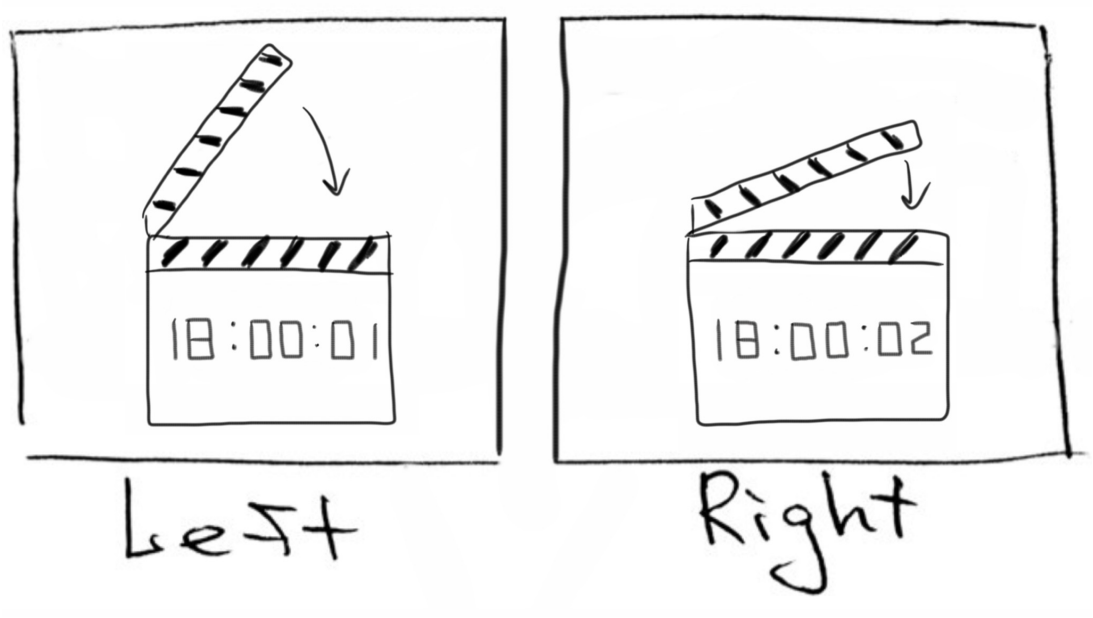


Figure 2.41: Schematic illustration of a stereo pair with temporal shift

This section compares films by the number and magnitude of temporal inconsistencies between views. We provide several metrics: cumulative duration of all scenes with temporal shifts (measured in seconds), maximum temporal shift throughout a movie (also measured in seconds) and an overall movie score that we compute as the sum of scores for individual scenes, each measured as the scene's temporal-shift magnitude multiplied by its duration. We show several scatterplots and bar charts that compare movies according to these metrics, similar to the diagrams in previous sections.

More information on temporal shifts in S3D video and our automatic detection method is in our eighth VQMT3D report [8].

See Temporal Shift Examples in Our Previous Reports

Several examples of scenes with noticeable temporal shifts can be found here:

- MSU VQMT3D Report 8 (June 2015, 366 pages, 361 figures) [8]

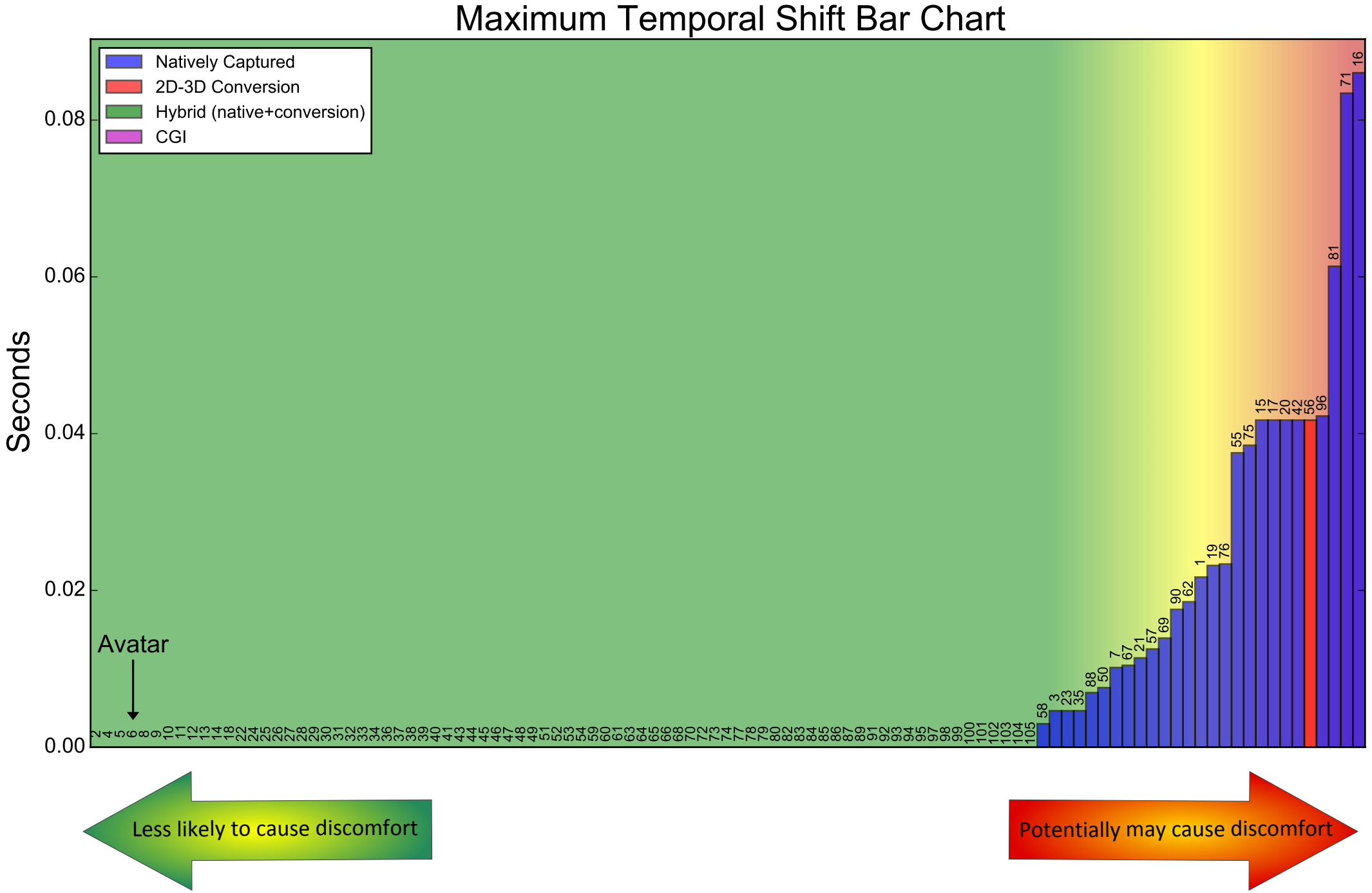


Figure 2.42: Bar chart with movies sorted by maximum temporal shift value in ascending order

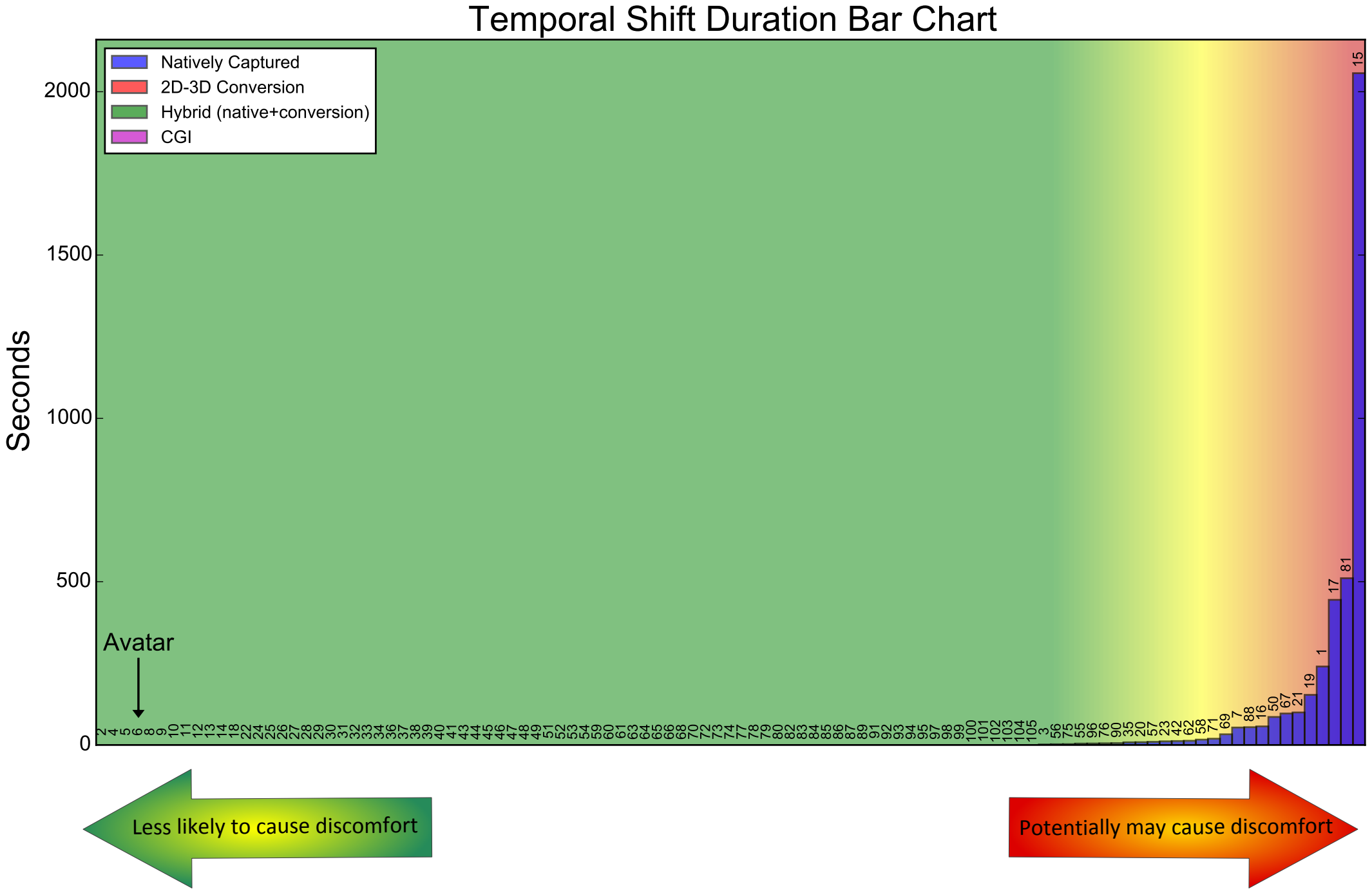


Figure 2.43: Bar chart with movies sorted by total duration of scenes with temporal shift in ascending order

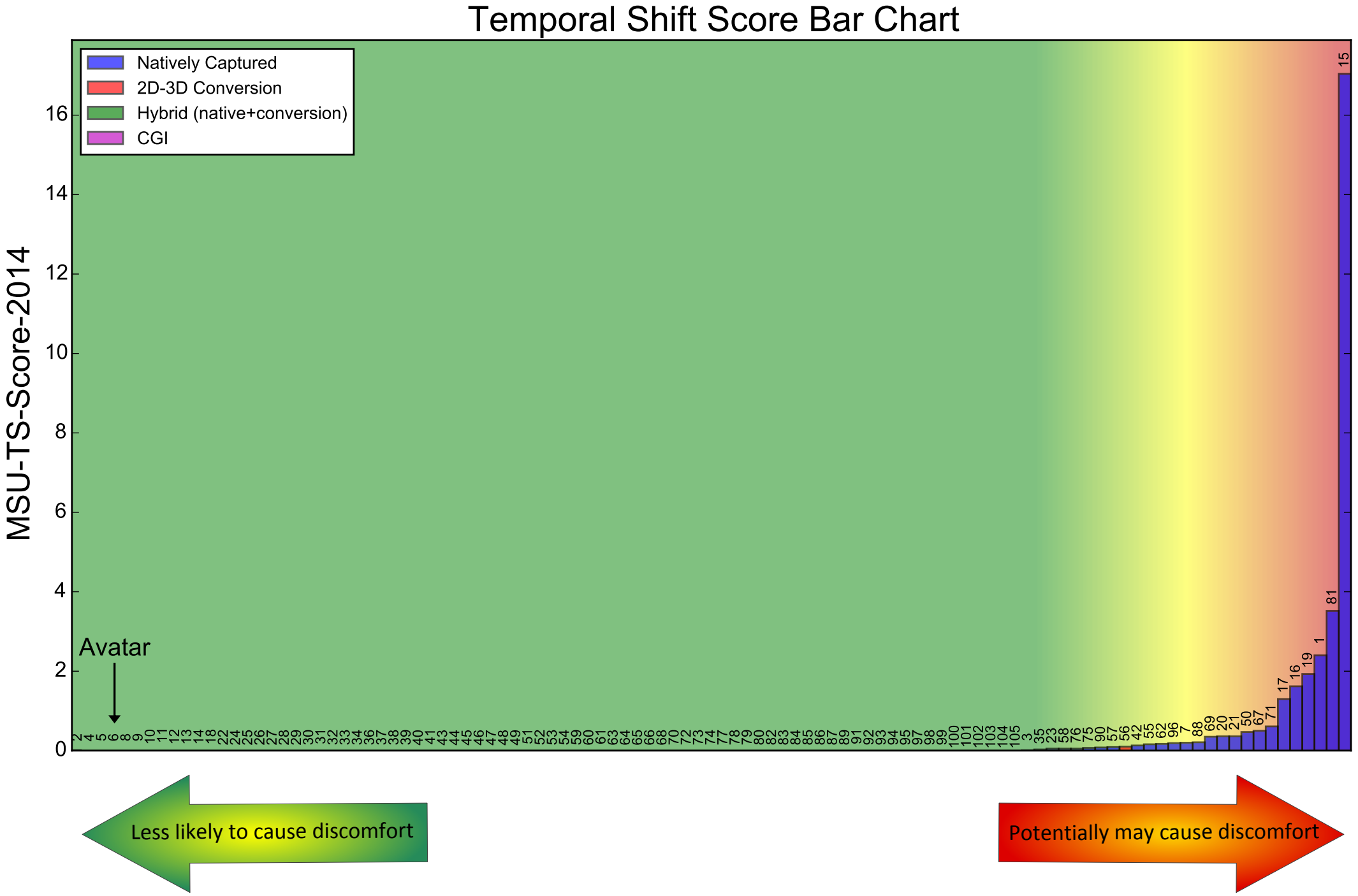


Figure 2.44: Bar chart with movies sorted by temporal shift score in ascending order

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

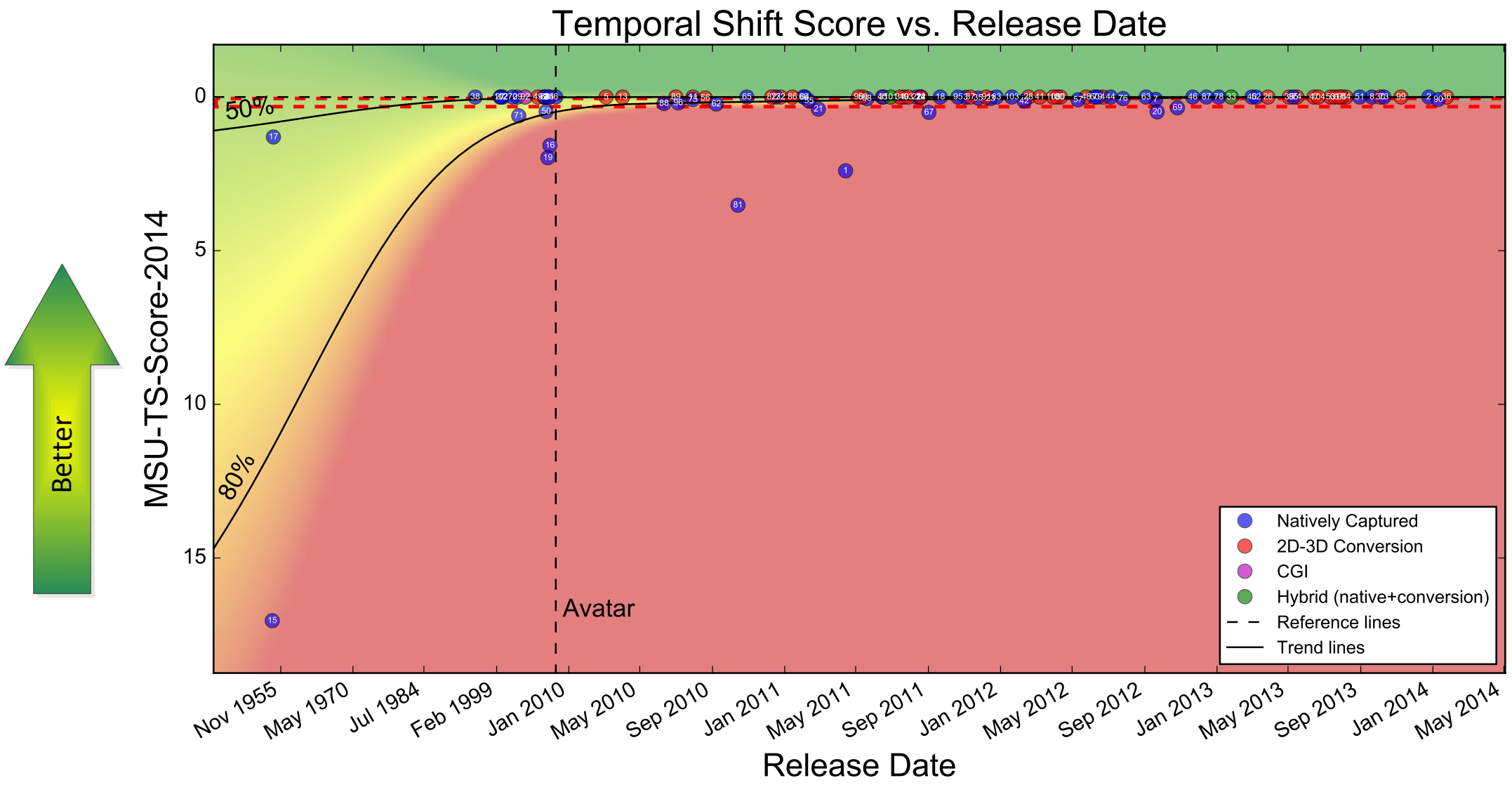


Figure 2.45: Diagram illustrating temporal shift score relative to movie release date

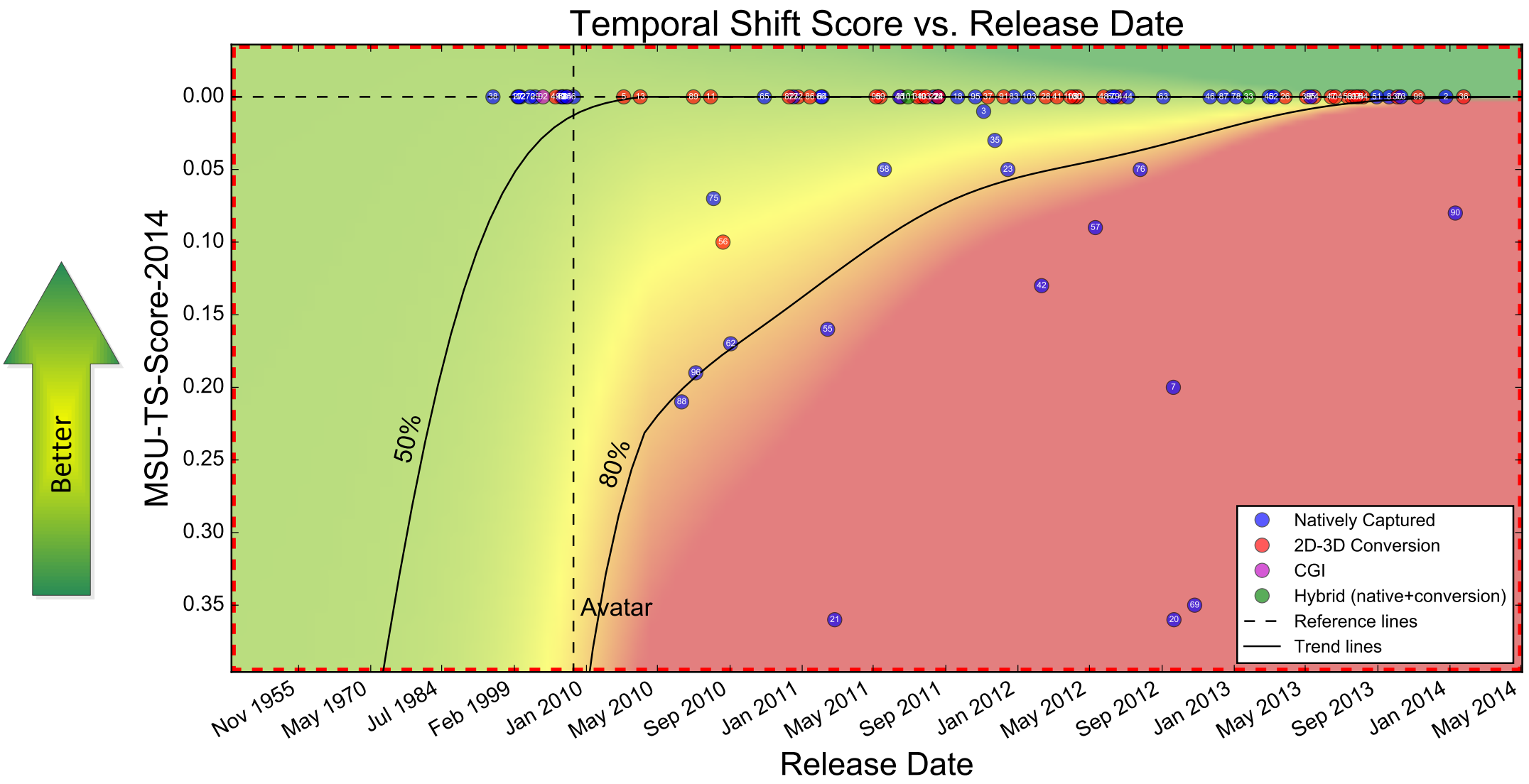


Figure 2.45a: Magnified fragment of the diagram in Figure 2.45

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

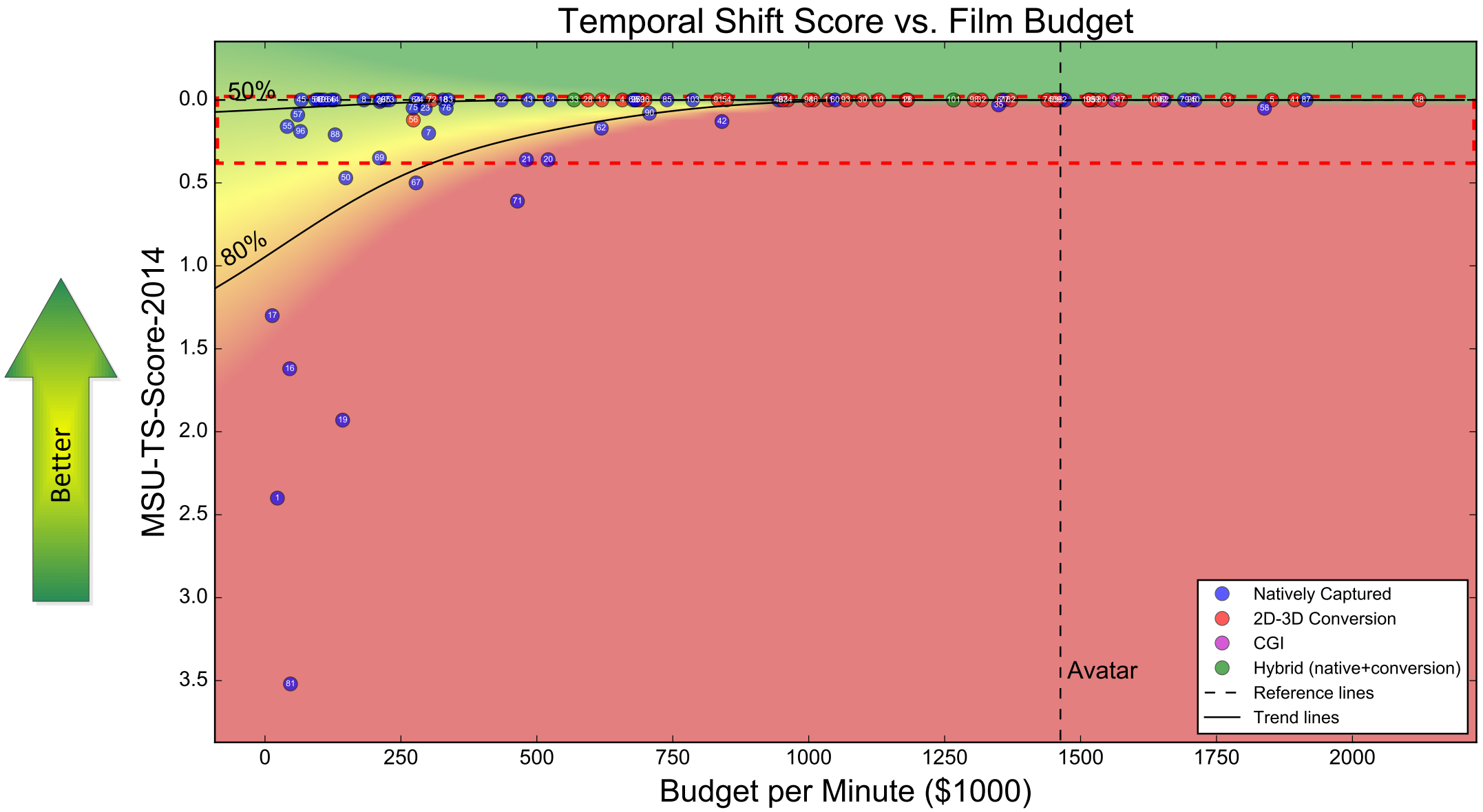


Figure 2.46: Diagram illustrating temporal shift score relative to movie budget (per minute)

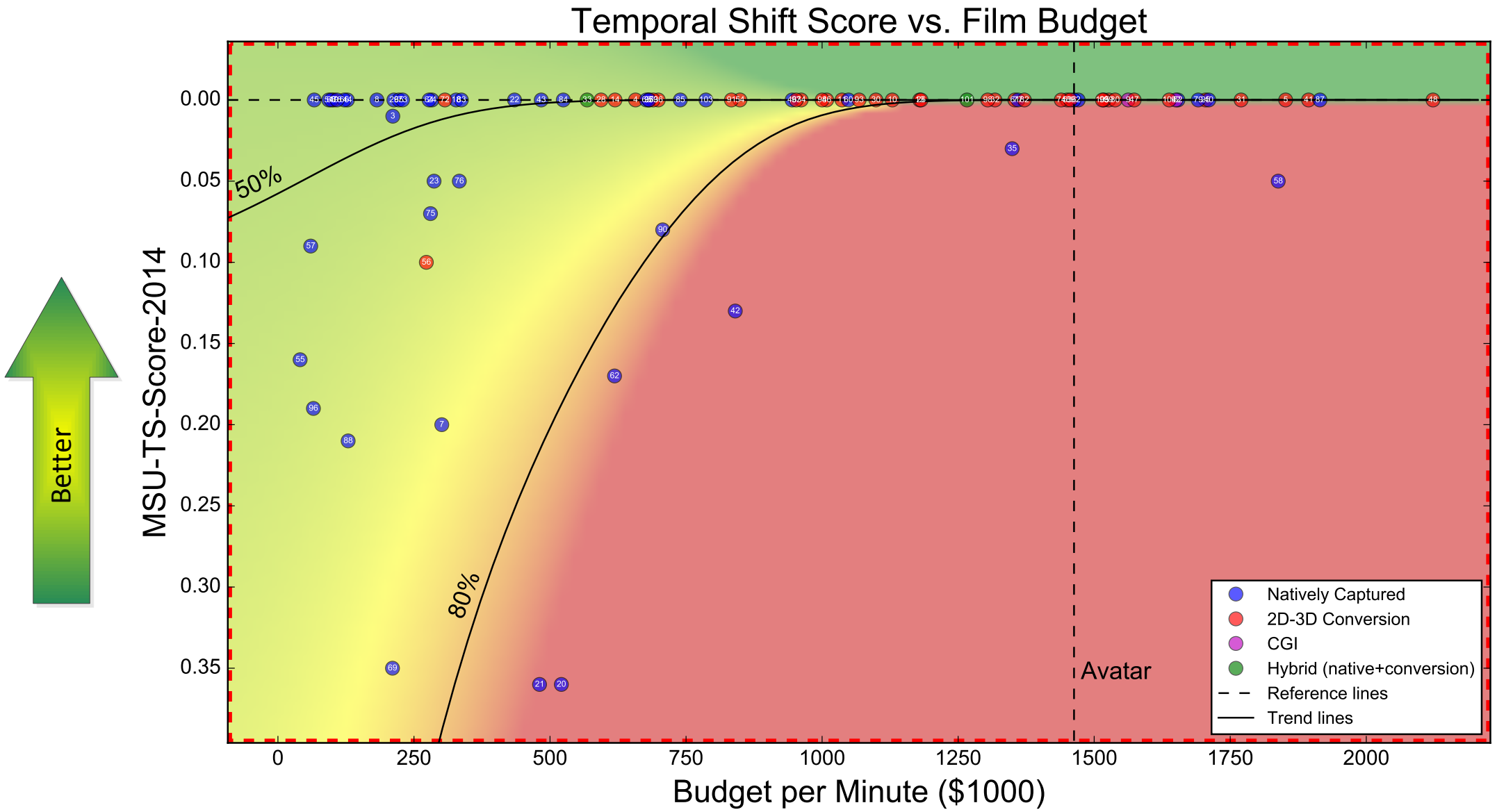


Figure 2.46a: Magnified fragment of the diagram in Figure 2.46

2.9 Channel Mismatch

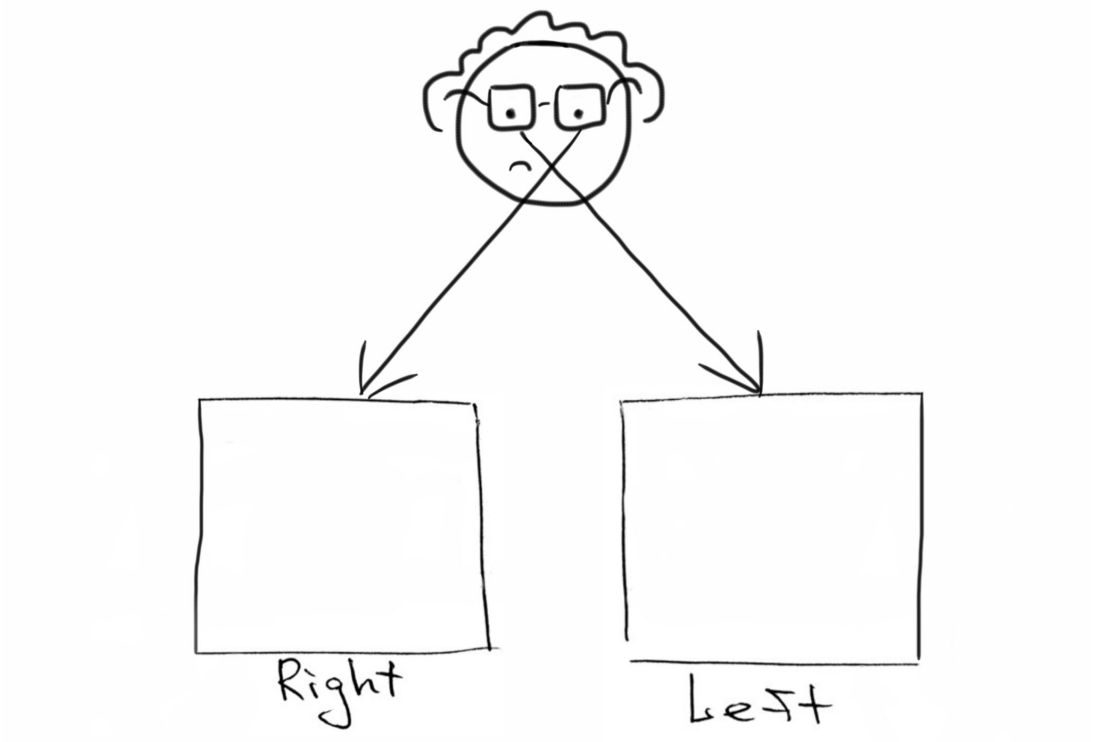


Figure 2.47: Schematic illustration of channel mismatch

A relatively rare but potentially annoying artifact is channel mismatch—the swapping of left and right views in stereoscopic video. The swap can be complete or it can be partial, meaning only some objects in the scene have improper depth values. We compare movies by the cumulative duration of all scenes containing channel mismatch and by channel-mismatch noticeability. To measure noticeability we conducted a subjective test with over 50 participants, who assessed each individual scene on a scale from 1 (channel mismatch is imperceptible) to 5 (channel mismatch is extremely annoying). We also computed the overall movie score in a manner similar to how we computed temporal shift (for all scenes with channel mismatch, we find the product of each scene's duration and channel-mismatch noticeability and then sum these products).

For more details on channel mismatch and our automatic-detection approach, consult the eighth VQMT3D report [8].

See Channel Mismatch Examples in Our Previous Reports
Several examples of scenes with channel mismatch can be found here:

- MSU VQMT3D Report 8 (June 2015, 366 pages, 361 figures) [8]

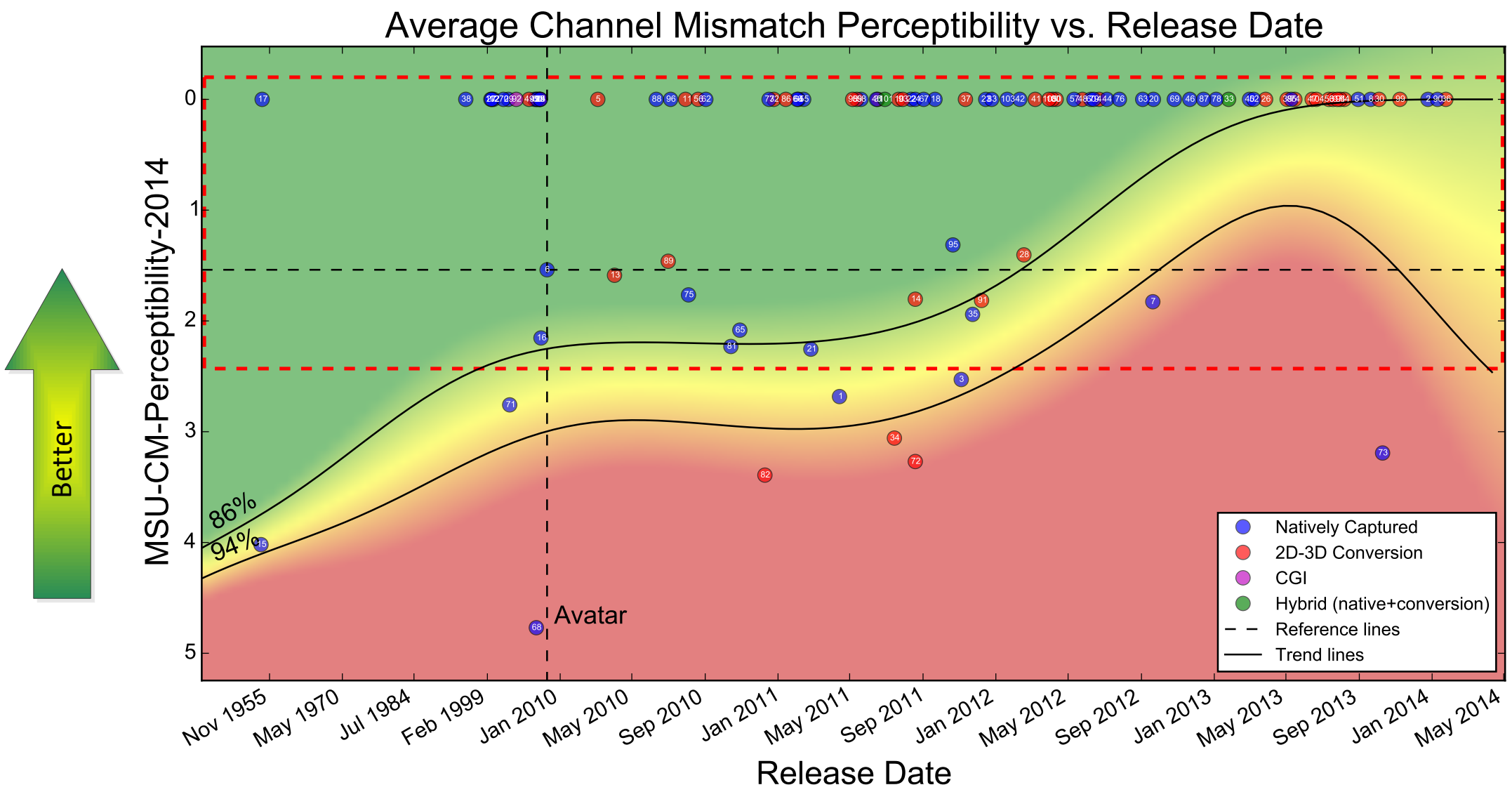


Figure 2.48: Diagram illustrating average perceptibility of detected channel mismatch relative to movie release date

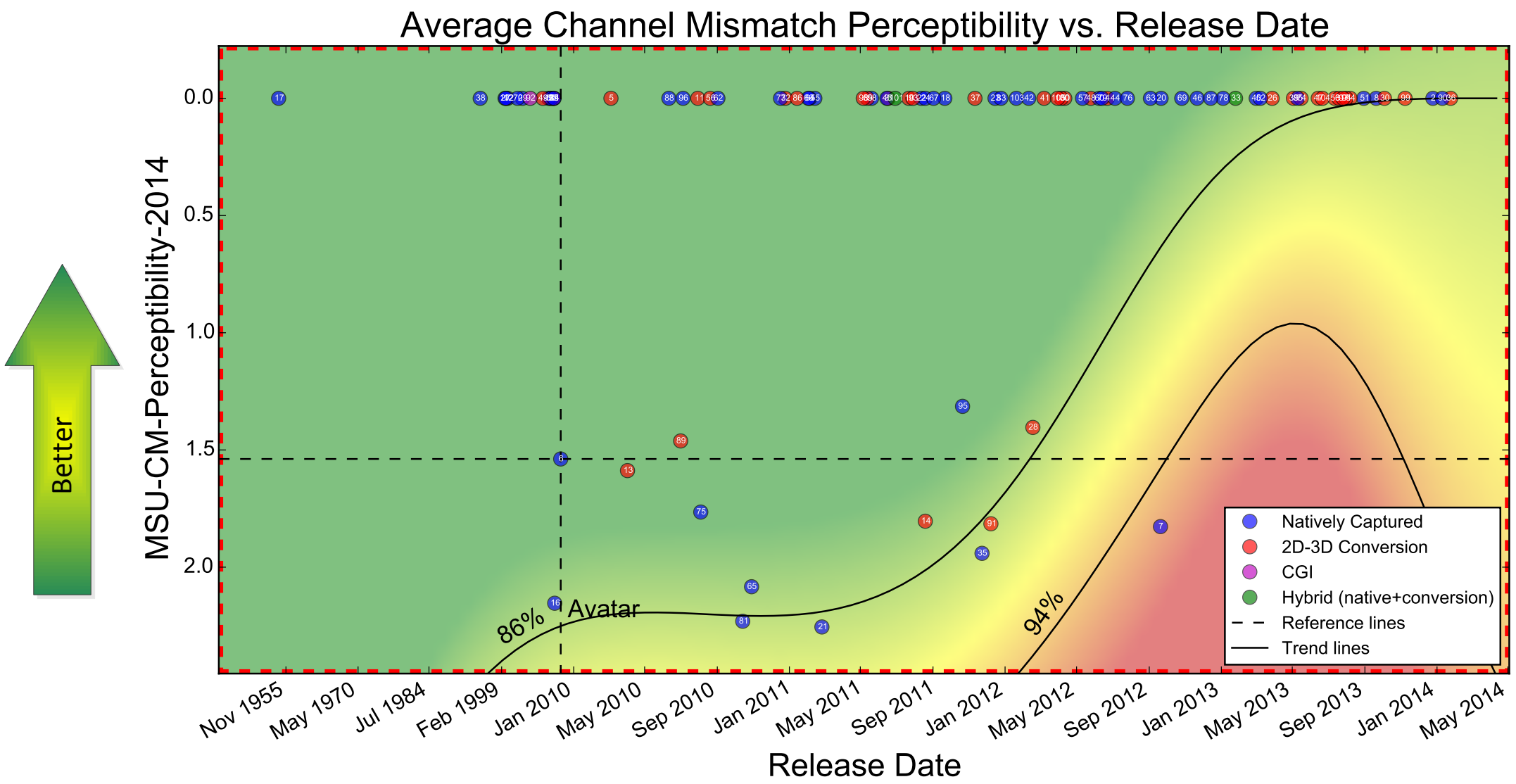


Figure 2.48a: Magnified fragment of the diagram in Figure 2.48

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

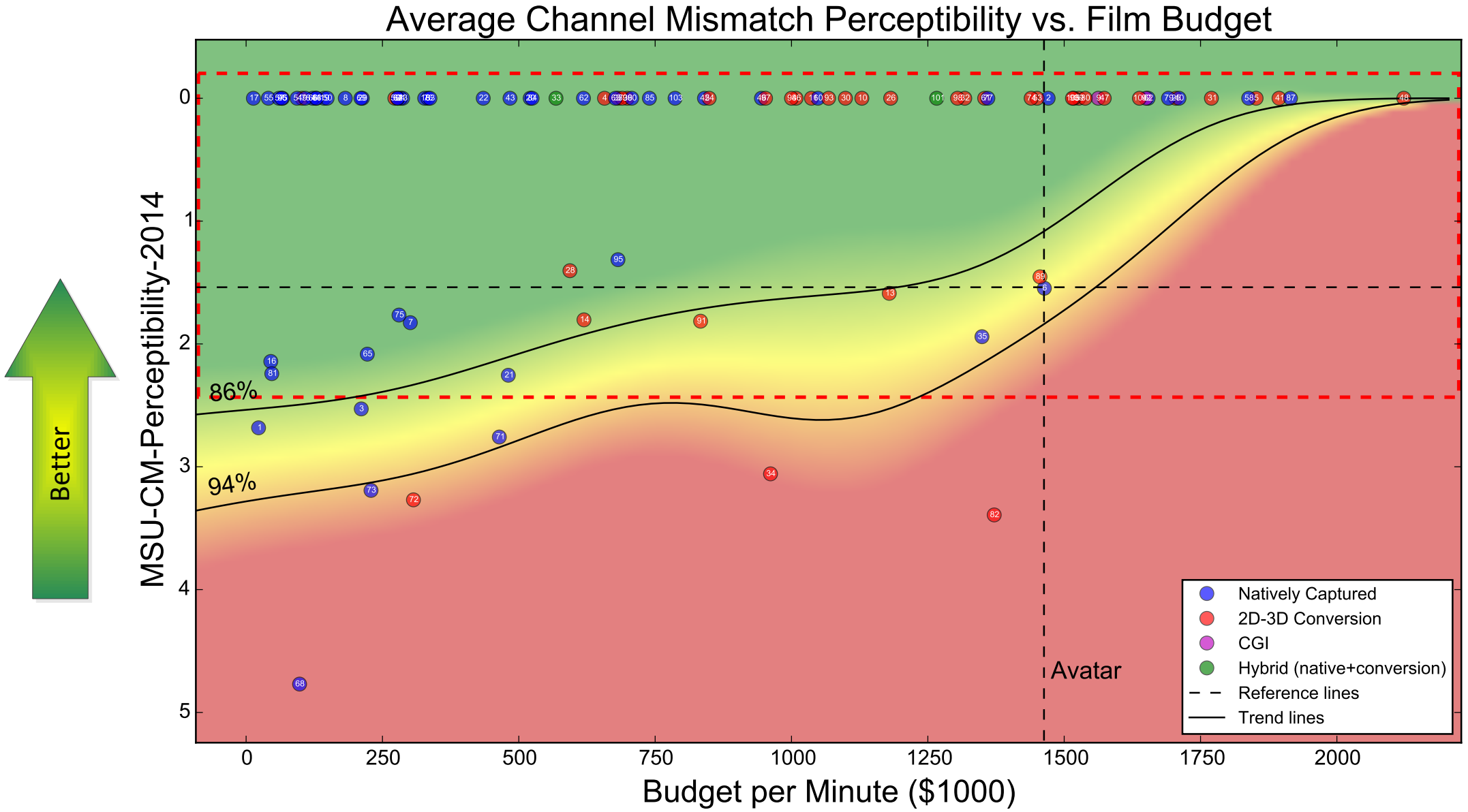


Figure 2.49: Diagram illustrating average perceptibility of detected channel mismatch relative to movie budget (per minute)

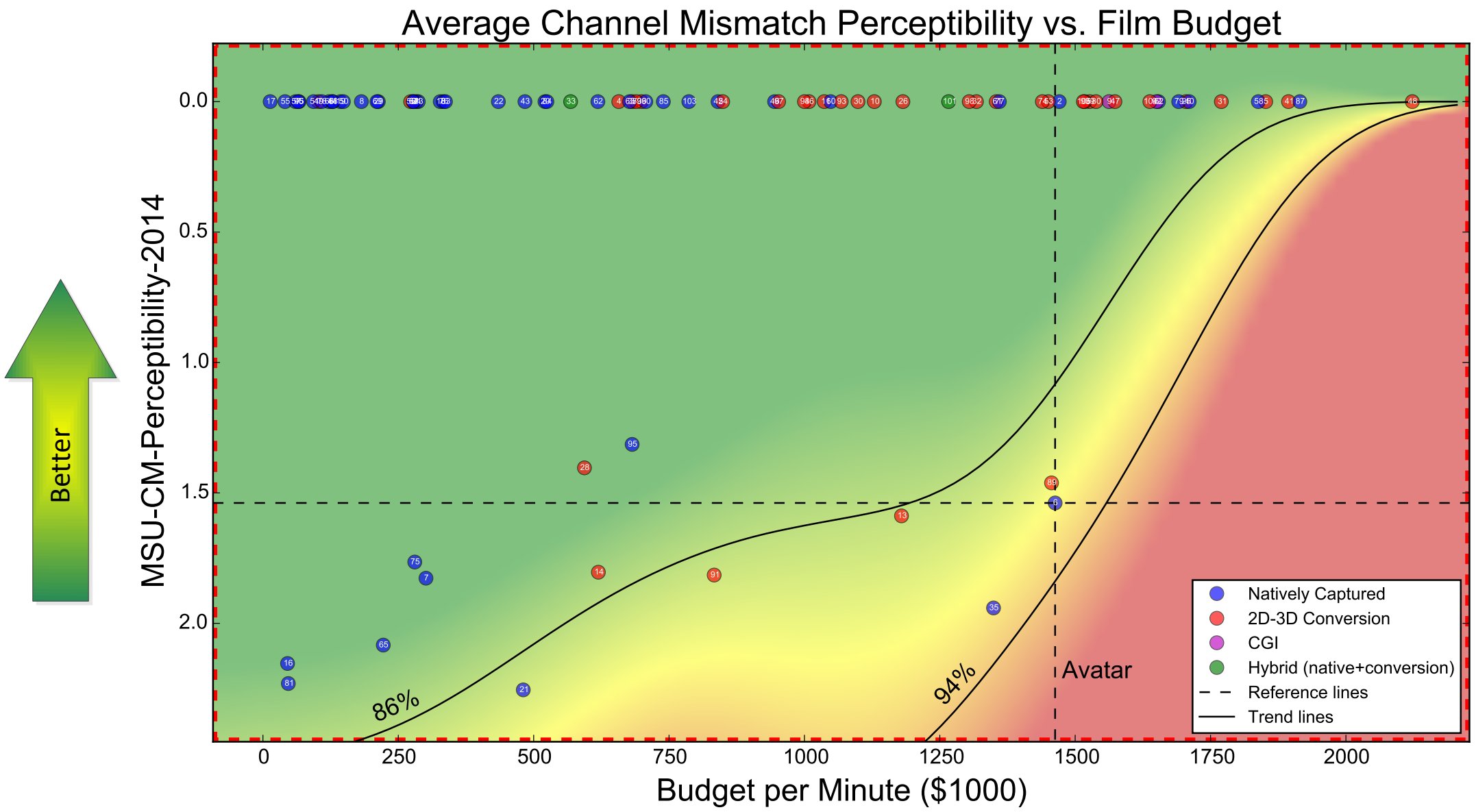


Figure 2.49a: Magnified fragment of the diagram in Figure 2.49

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

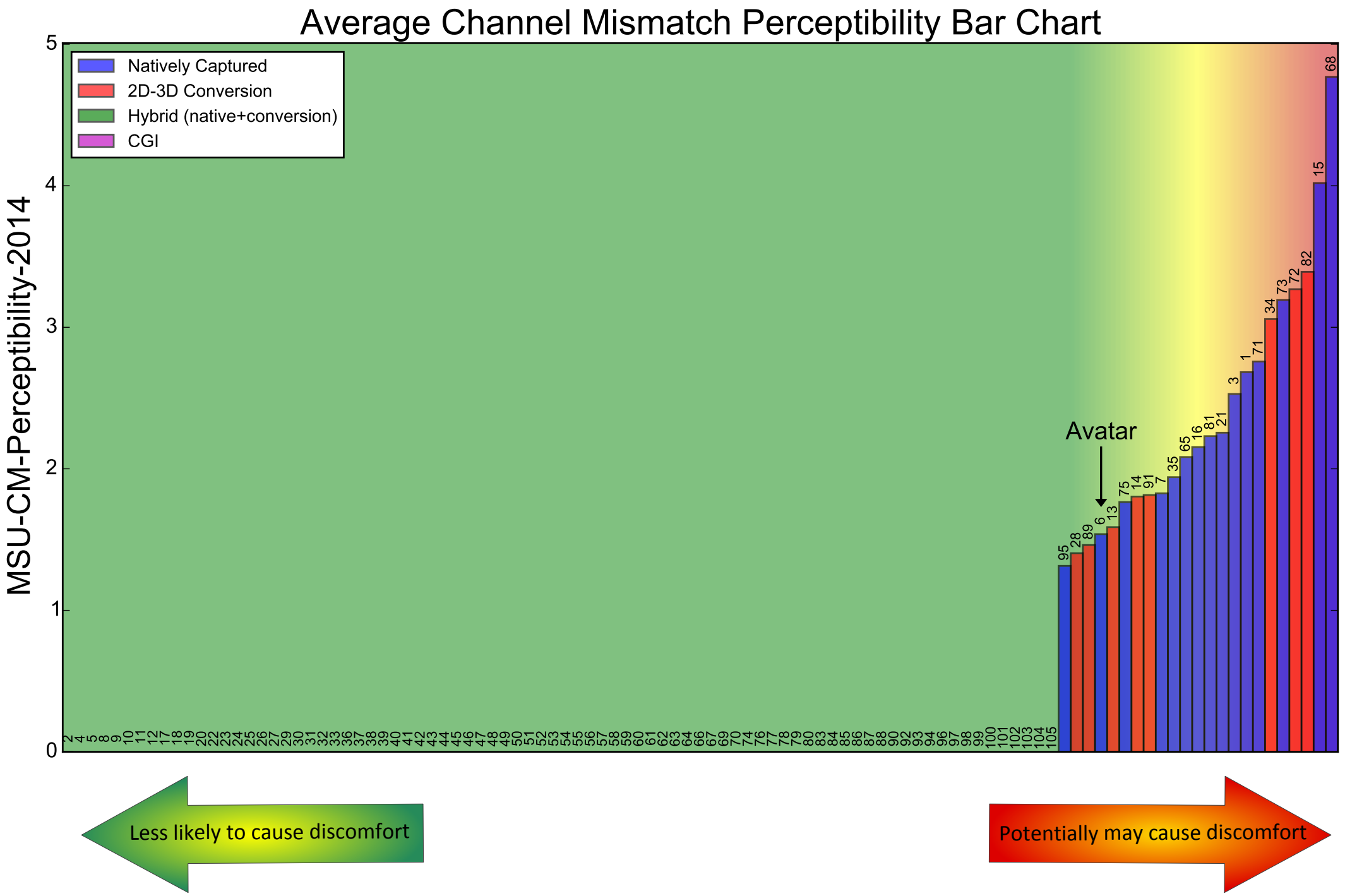


Figure 2.50: Bar chart with movies sorted by average perceptibility of detected channel mismatch in ascending order

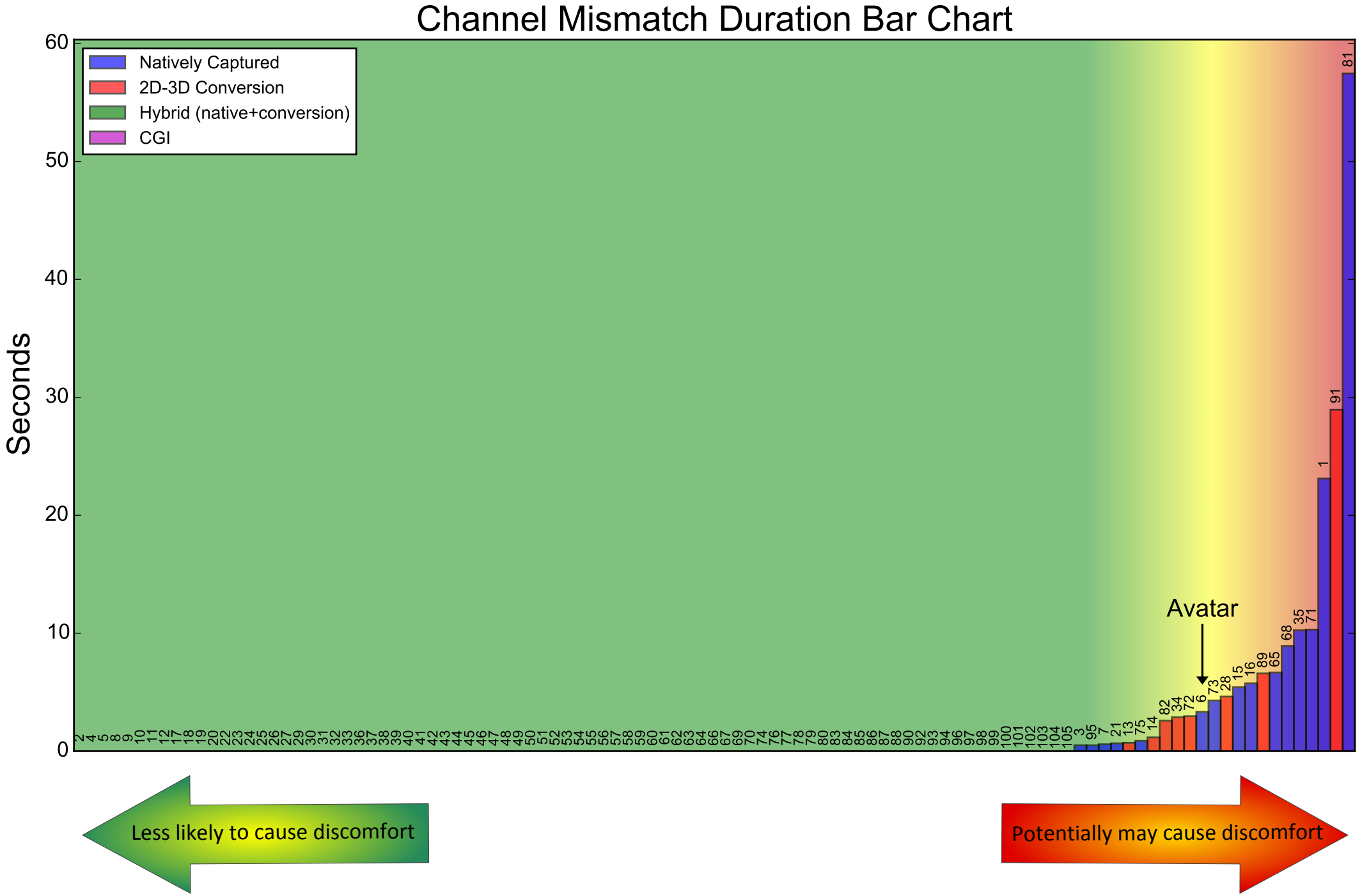


Figure 2.51: Bar chart with movies sorted by total duration of scenes with channel mismatch in ascending order

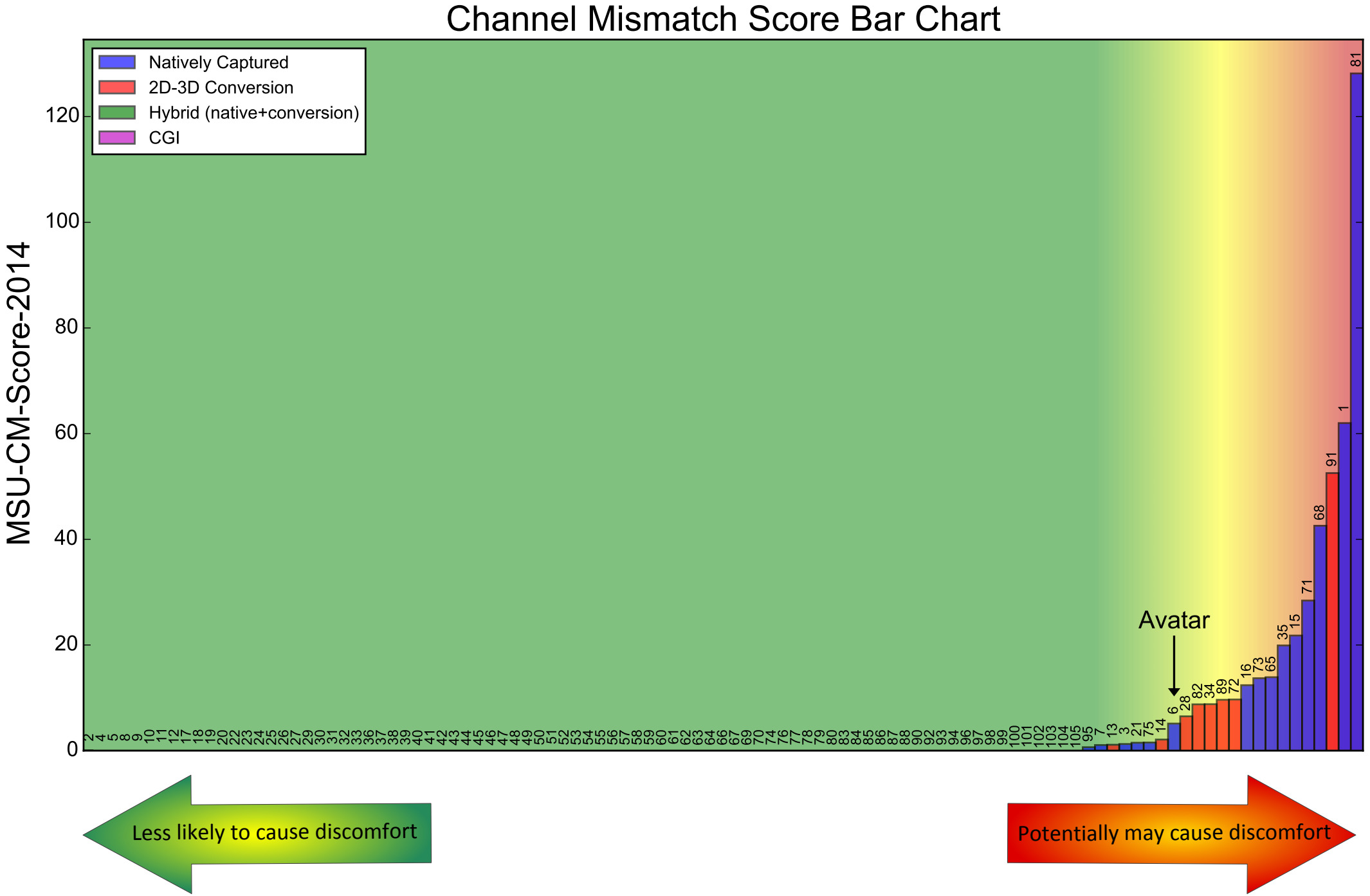


Figure 2.52: Bar chart with movies sorted by channel mismatch score in ascending order

2.10 Crosstalk

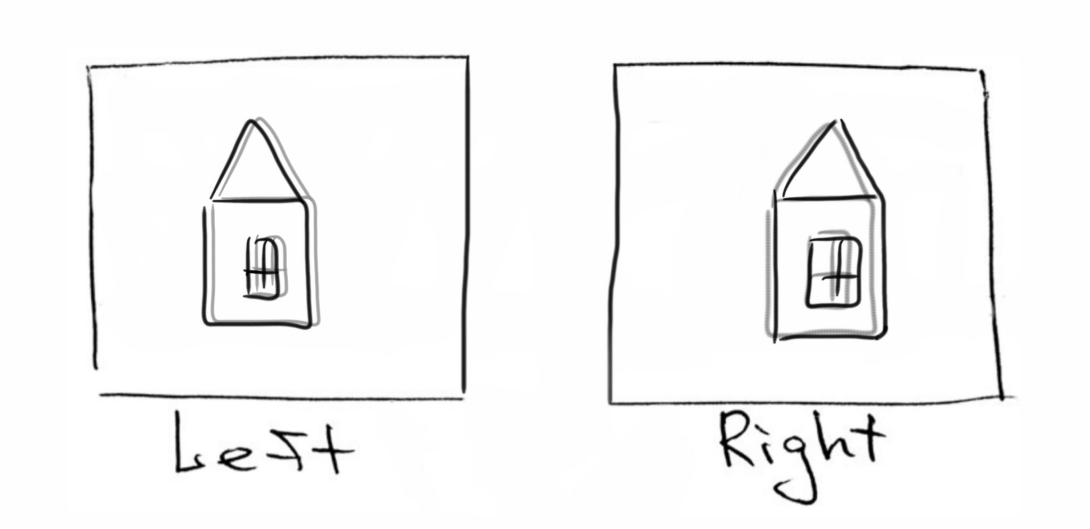


Figure 2.53: Schematic illustration of a stereo pair with visible crosstalk

This section shows results from our movie comparison in terms of potential perceived crosstalk. The main idea is that the amount of perceived crosstalk depends not only on the viewing environment but also on the content. For example, high-contrast shots with a large depth budget tend to cause considerable discomfort owing to crosstalk.

Crosstalk-metric values are dimensionless and represent the strength of perceived crosstalk when the viewer sees the content on a crosstalk-prone S3D display. Higher values indicate greater perceived crosstalk. For more details on stereoscopic crosstalk and our metric, see the eighth VQMT3D report [8].

To compare movies by perceived crosstalk, we again use the now familiar four charts: two straightforward scatterplots illustrating average crosstalk values relative to movie-release date and budget, a bar chart with average crosstalk values, and a stacked bar chart illustrating the metric-value distributions for different movies.

See Examples of Shots with Potentially High Crosstalk in Our Previous Reports
Several examples of shots, where the crosstalk may cause significant discomfort and crosstalk noticeability maps can be found here:

- MSU VQMT3D Report 8 (June 2015, 366 pages, 361 figures) [8]

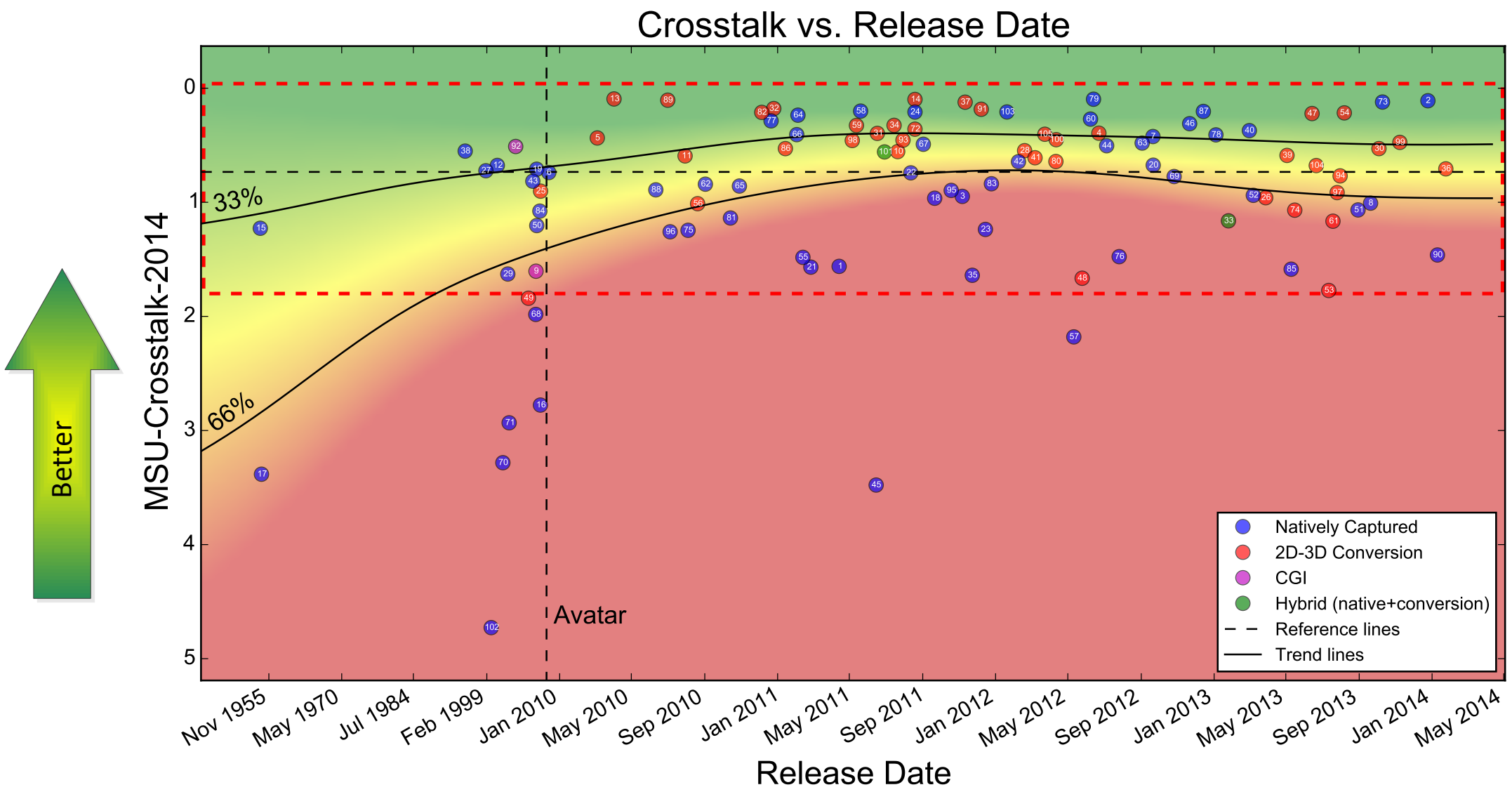


Figure 2.54: Diagram illustrating crosstalk metric value relative to movie release date

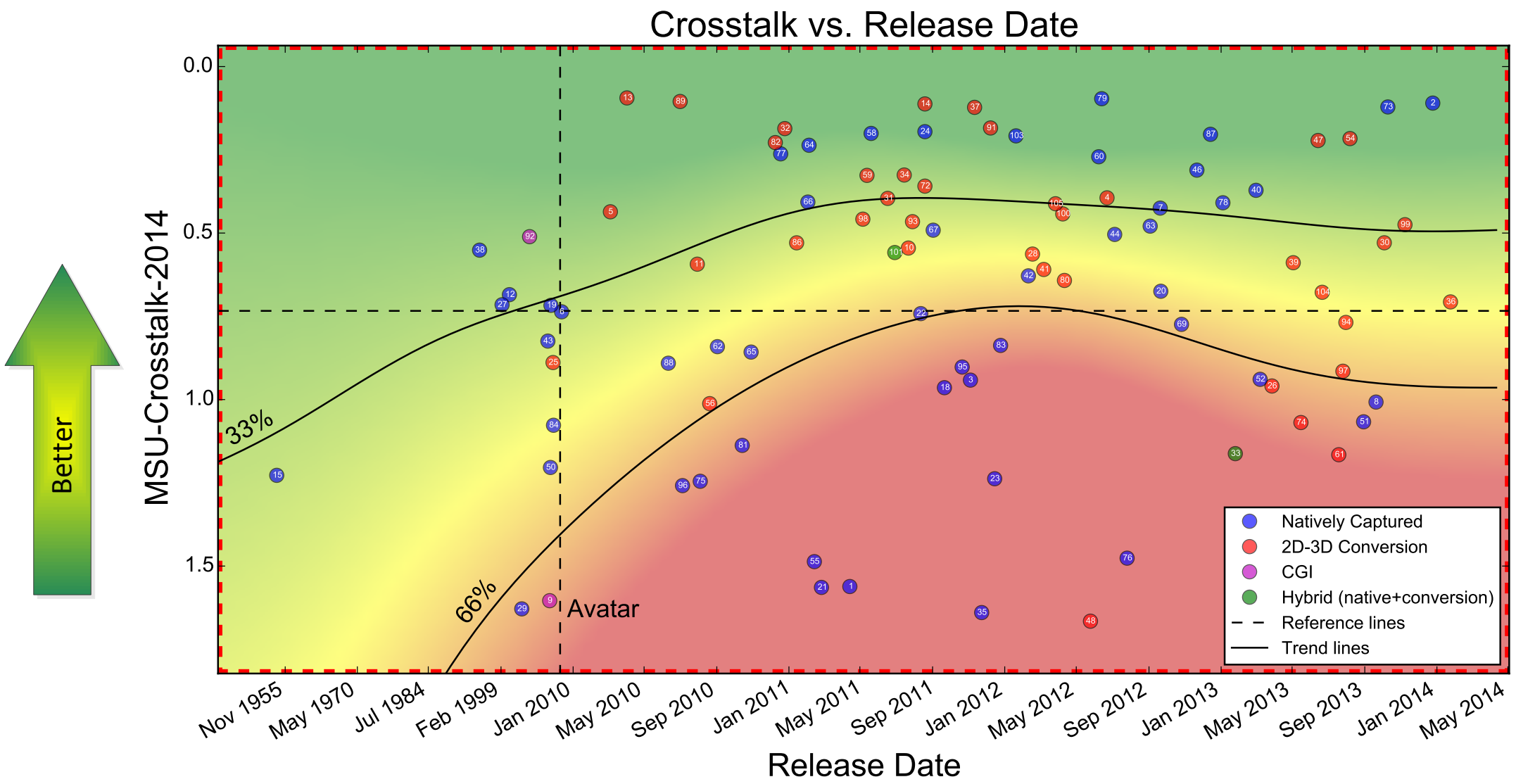


Figure 2.54a: Magnified fragment of the diagram in Figure 2.54

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

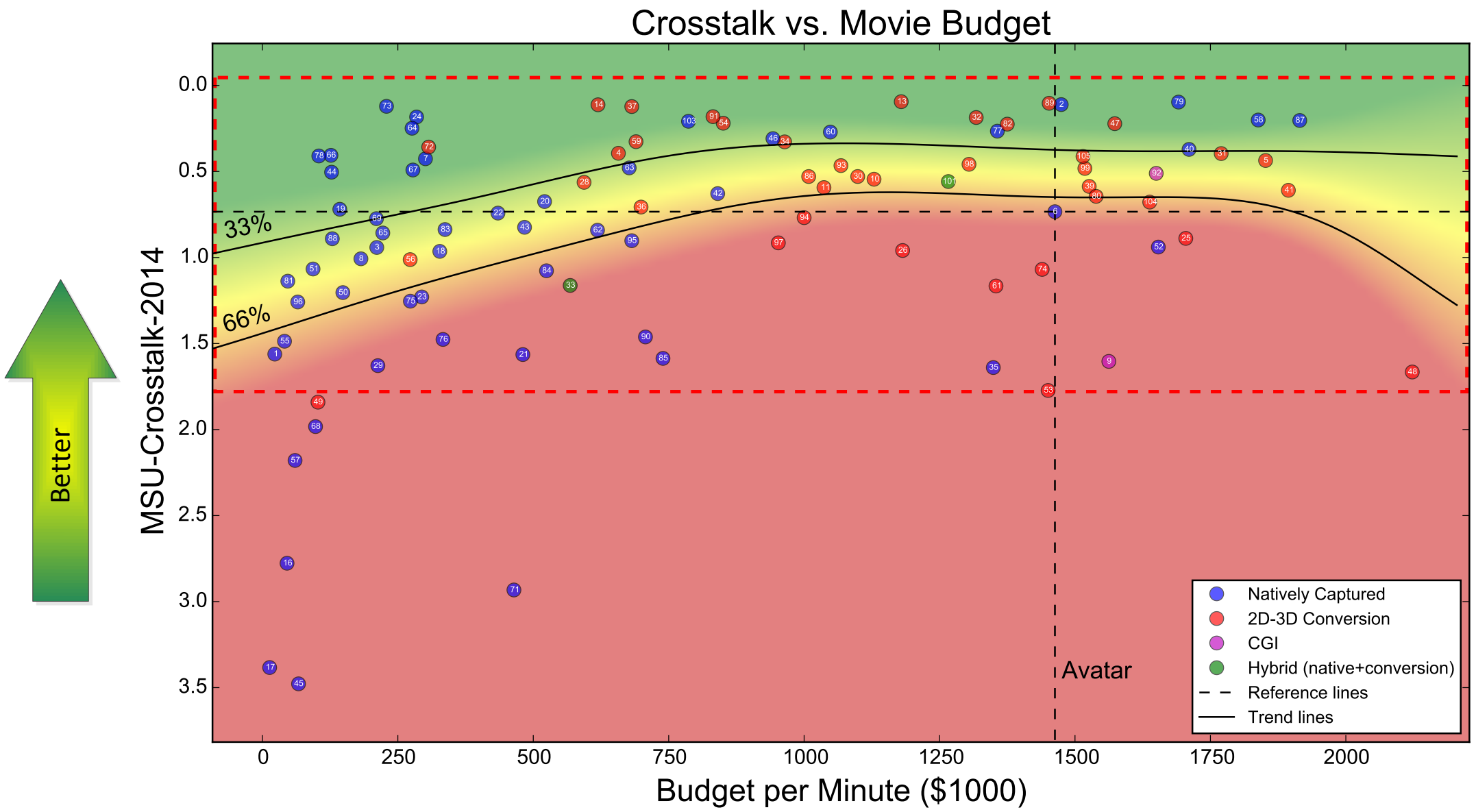


Figure 2.55: Diagram illustrating crosstalk metric value relative to movie budget (per minute)

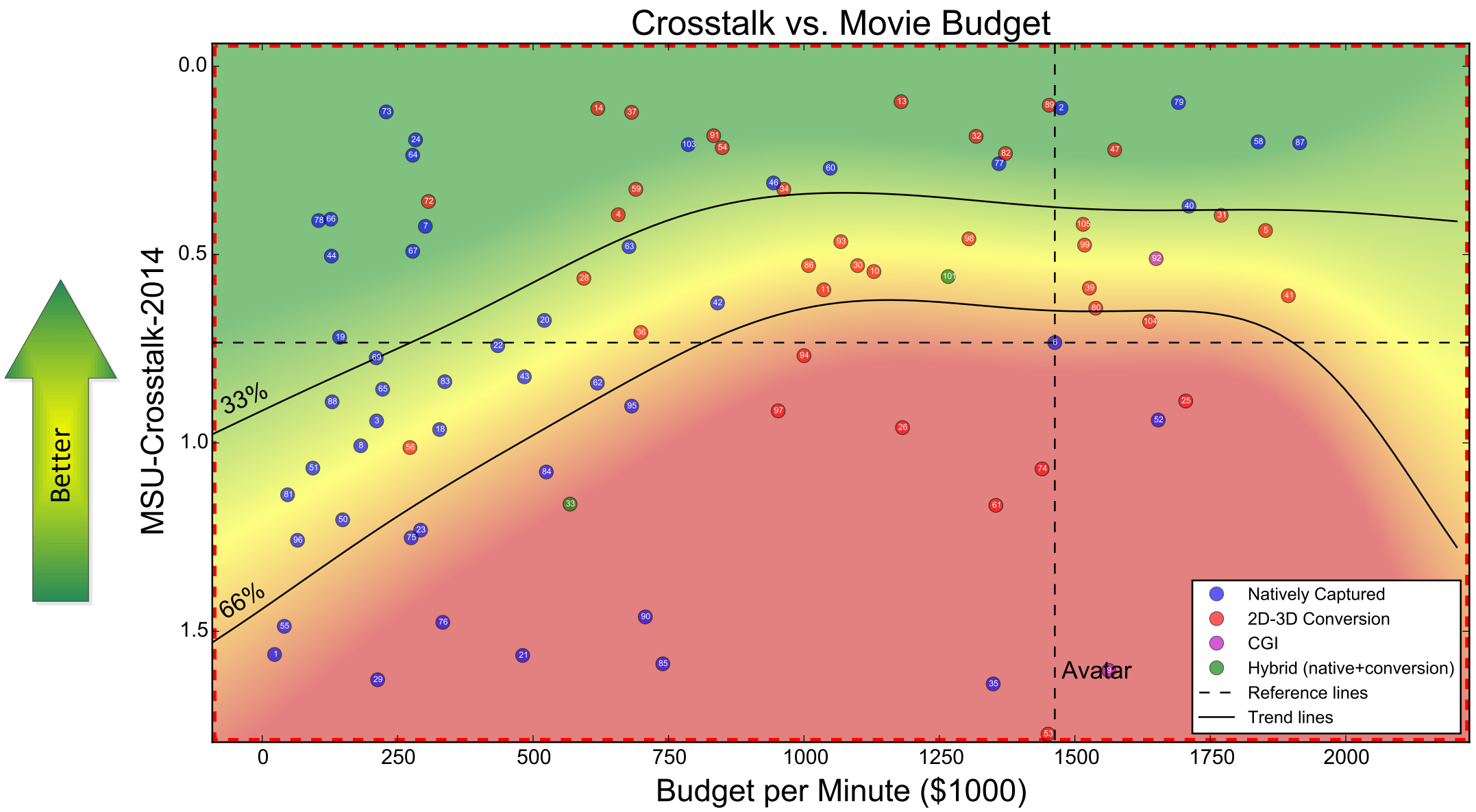


Figure 2.55a: Magnified fragment of the diagram in Figure 2.55

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

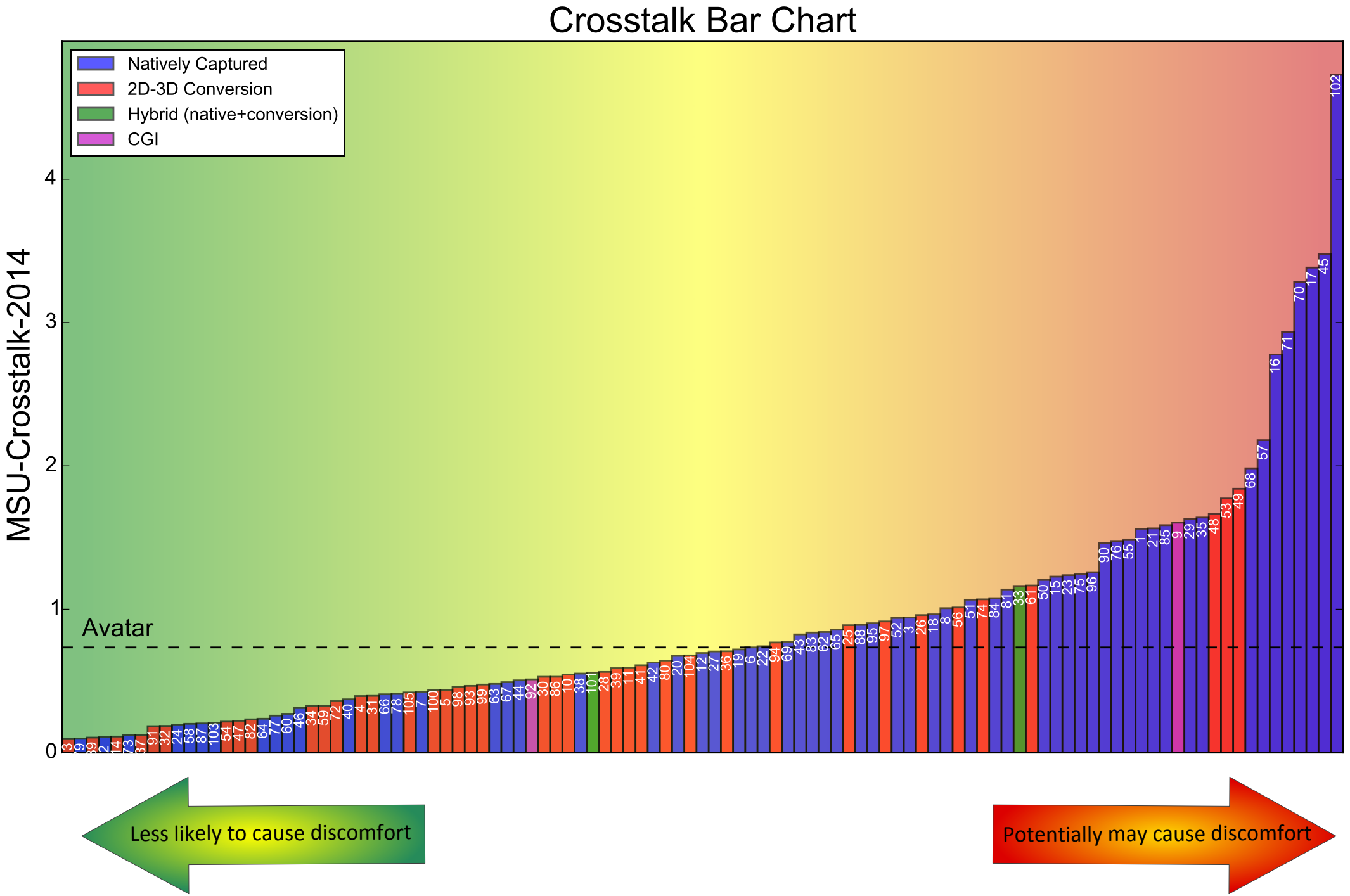


Figure 2.56: Bar chart with movies sorted by average crosstalk metric value in ascending order

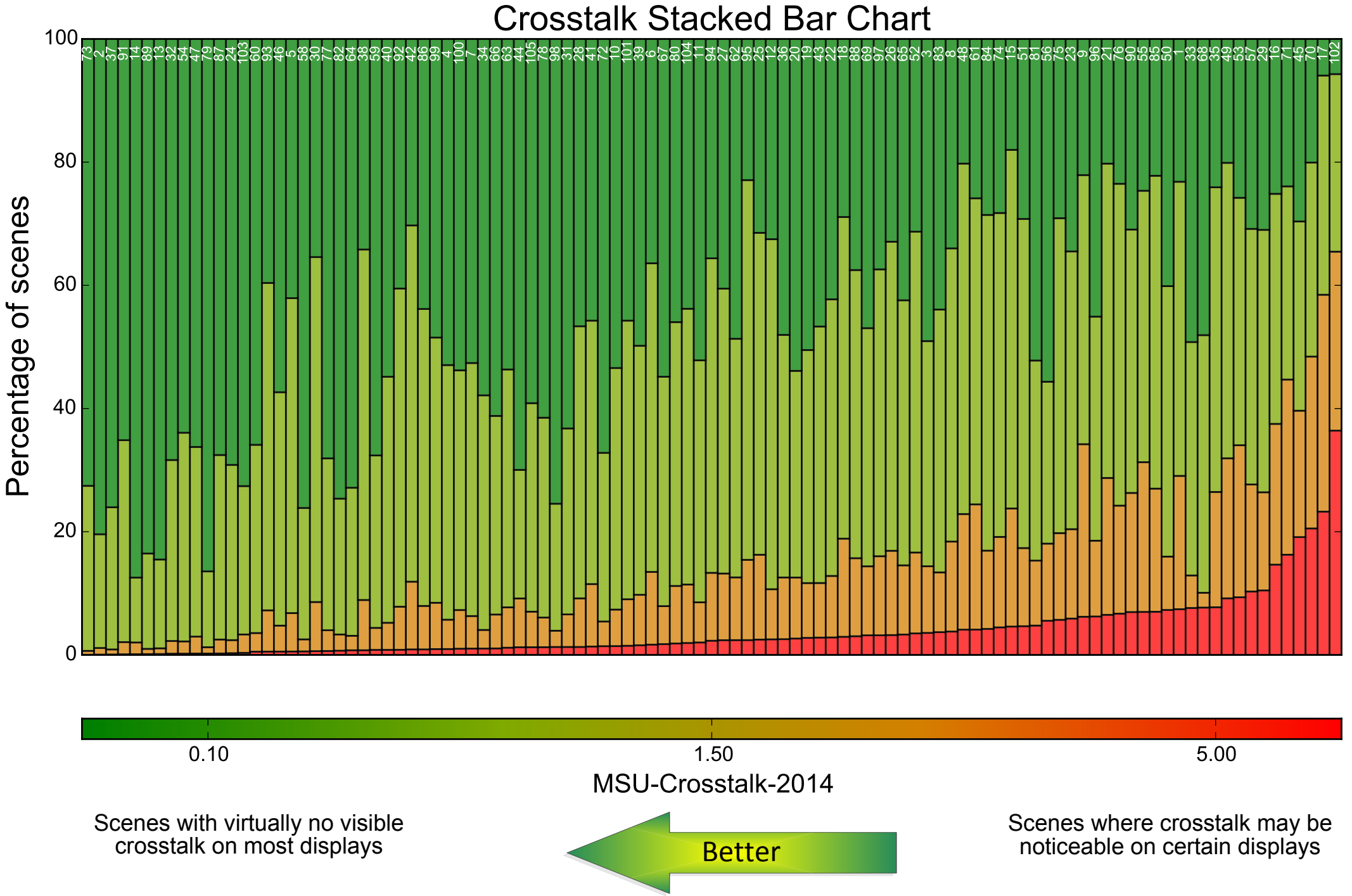


Figure 2.57: Stacked bar chart with movies sorted by the amount of scenes with potentially noticeable crosstalk

2.11 Average Brightness

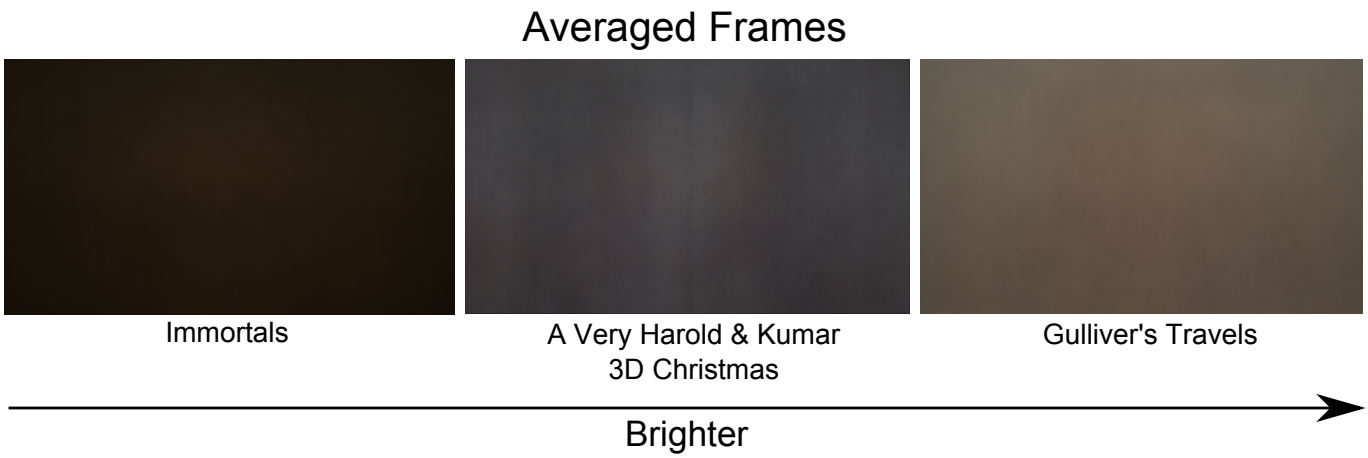


Figure 2.58: Illustration of difference in average brightness for selected movies. Each image represents an an average of all frames in the respective movie.

Films with many dark scenes tend to induce additional viewer fatigue. This problem is especially common in S3D content, as most stereoscopic-display technologies reduce the image's perceived brightness considerably. Therefore, comparing movies by average brightness is helpful even though brightness usually depends on creative choices made throughout the film.

Our brightness comparison employs the same four charts as the previous section (Crosstalk). To measure this characteristic we use luminance values normalized from 0 (completely black frame) to 255 (completely white frame).

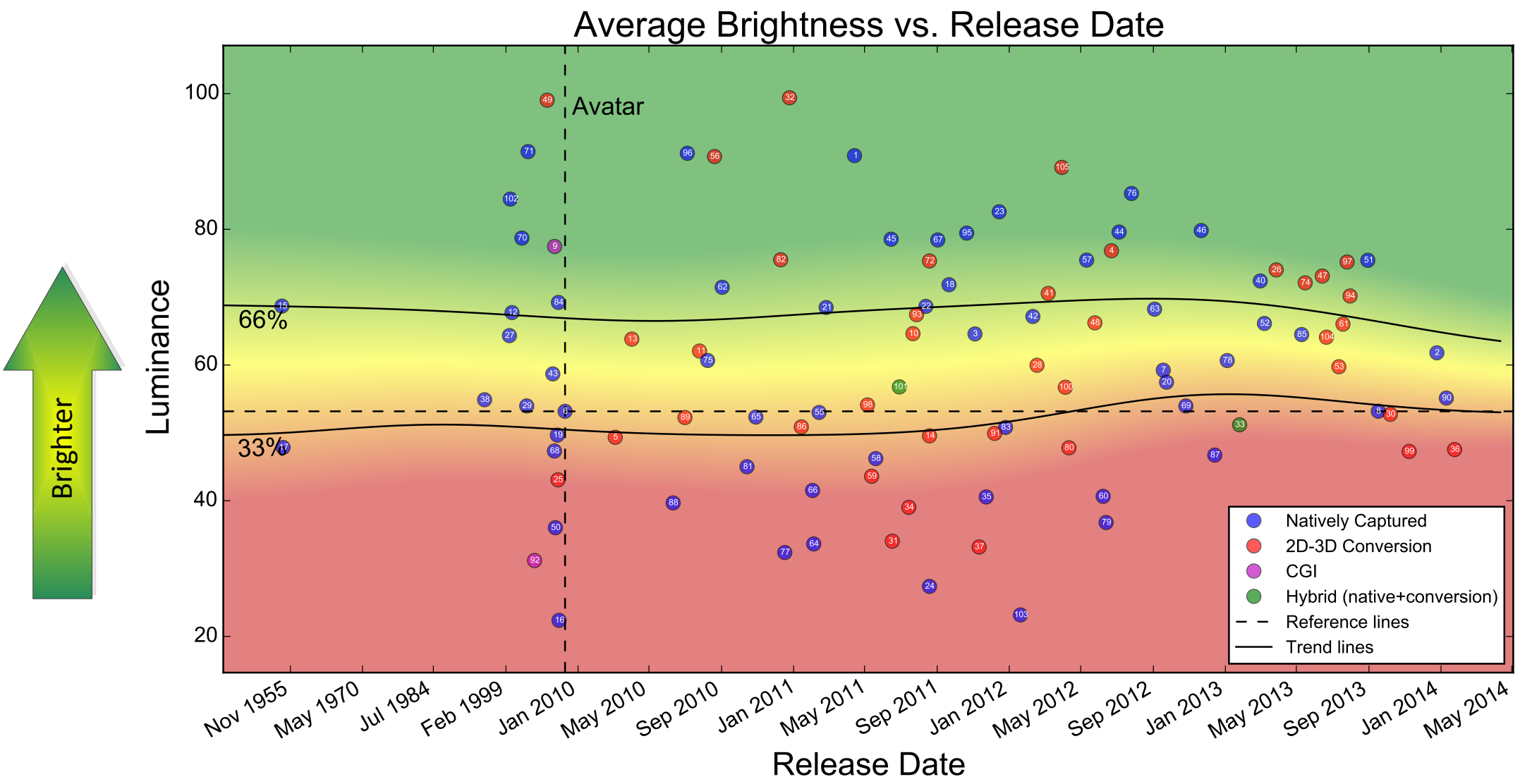


Figure 2.59: Diagram illustrating average brightness value relative to movie release date

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy (Apr 2011)
2: 47 Ronin (Dec 2013)
3: A Very Harold & Kumar 3D Christmas (Nov 2011)
6: Avatar (Dec 2009)
7: Bait (Sep 2012)
8: Battle of the Year (Sep 2013)
12: Cirque du Soleil: Journey of Man (May 2000)
15: Creature from the Black Lagoon (Mar 1954)
16: Dark Country (Oct 2009)
17: Dial M for Murder (May 1954)
18: Dolphin Tale (Sep 2011)
19: Dolphins and Whales 3D: Tribes of the Ocean (Jun 2009)
20: Dredd (Sep 2012)
21: Drive Angry (Feb 2011)
22: Final Destination 5 (Aug 2011)
23: Flying Swords of Dragon Gate (Dec 2011)
24: Fright Night (Aug 2011)
27: Galapagos: The Enchanted Voyage (Oct 1999)
29: Ghosts of the Abyss (Apr 2003)
35: Hugo (Nov 2011)
38: Into the Deep (Nov 1994)
40: Jack the Giant Slayer (Mar 2013)
42: Journey 2: The Mysterious Island (Feb 2012)
43: Journey to the Center of the Earth (Jul 2008)
44: Katy Perry: Part of Me (Jul 2012)
45: Legends of Flight (Jun 2011)
46: Life of Pi (Nov 2012)
50: My Bloody Valentine (Jan 2009)
51: One Direction: This Is Us (Aug 2013)
52: Oz the Great and Powerful (Mar 2013)
55: Pina (Feb 2011)
57: Piranha 3DD (May 2012)
58: Pirates of the Caribbean: On Stranger Tides (May 2011)
60: Prometheus (Jun 2012)
62: Resident Evil: Afterlife (Sep 2010)
63: Resident Evil: Retribution (Sep 2012)
64: Sanctum (Feb 2011)
65: Saw 3D: The Final Chapter (Oct 2010)
66: Sea Rex 3D: Journey to a Prehistoric World (Feb 2011)
67: Shark Night 3D (Sep 2011)
68: Sharks 3D (Nov 2008)
69: Silent Hill: Revelation 3D (Oct 2012)
70: Space Station 3D (Apr 2002)
71: Spy Kids 3-D: Game Over (Jul 2003)
73: Stalingrad (Oct 2013)
75: Step Up 3D (Aug 2010)
76: Step Up Revolution (Jul 2012)
77: TRON: Legacy (Dec 2010)
78: Texas Chainsaw 3D (Jan 2013)
79: The Amazing Spiderman (Jun 2012)
81: The Child's Eye (Oct 2010)
83: The Darkest Hour (Dec 2011)
84: The Final Destination (Aug 2009)
85: The Great Gatsby (May 2013)
87: The Hobbit: An Unexpected Journey (Dec 2012)
88: The Hole (Jun 2010)
90: The Legend of Hercules (Jan 2014)
95: The Three Musketeers (Oct 2011)
96: The Ultimate Wave Tahiti (Jul 2010)
102: Ultimate G's (Jan 2000)
103: Underworld: Awakening (Jan 2012)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters (Jan 2013)
101: Transformers: Dark of the Moon (Jun 2011)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter (Jun 2012)
5: Alice in Wonderland (Mar 2010)
10: Captain America: The First Avenger (Jul 2011)
11: Cats & Dogs: The Revenge of Kitty Galore (Jul 2010)
13: Clash of the Titans (Apr 2010)
14: Conan the Barbarian (Aug 2011)
25: G-Force (Jul 2009)
26: G.I. Joe: Retaliation (Mar 2013)
28: Ghost Rider: Spirit of Vengeance (Feb 2012)
30: Gravity (Oct 2013)
31: Green Lantern (Jun 2011)
32: Gulliver's Travels (Dec 2010)
34: Harry Potter and the Deathly Hallows: Part 2 (Jul 2011)
36: I, Frankenstein (Jan 2014)
37: Immortals (Nov 2011)
39: Iron Man 3 (May 2013)
41: John Carter (Mar 2012)
47: Man of Steel (Jun 2013)
48: Men in Black 3 (May 2012)
49: Mummies: Secrets of the Pharaohs (May 2007)
53: Pacific Rim (Jul 2013)
54: Percy Jackson: Sea of Monsters (Aug 2013)
56: Piranha 3D (Aug 2010)
59: Priest (May 2011)
61: R.I.P.D. (Jul 2013)
72: Spy Kids: All the Time in the World in 4D (Aug 2011)
74: Star Trek Into Darkness (May 2013)
80: The Avengers (Apr 2012)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader (Dec 2010)
86: The Green Hornet (Jan 2011)
89: The Last Airbender (Jul 2010)
91: The Nutcracker in 3D (Dec 2011)
93: The Smurfs (Jul 2011)
94: The Smurfs 2 (Jul 2013)
97: The Wolverine (Jul 2013)
98: Thor (May 2011)
99: Thor: The Dark World (Nov 2013)
100: Titanic (Apr 2012)
104: World War Z (Jun 2013)
105: Wrath of the Titans (Mar 2012)

CGI

9: Bolt (Nov 2008)
92: The Polar Express (Nov 2004)

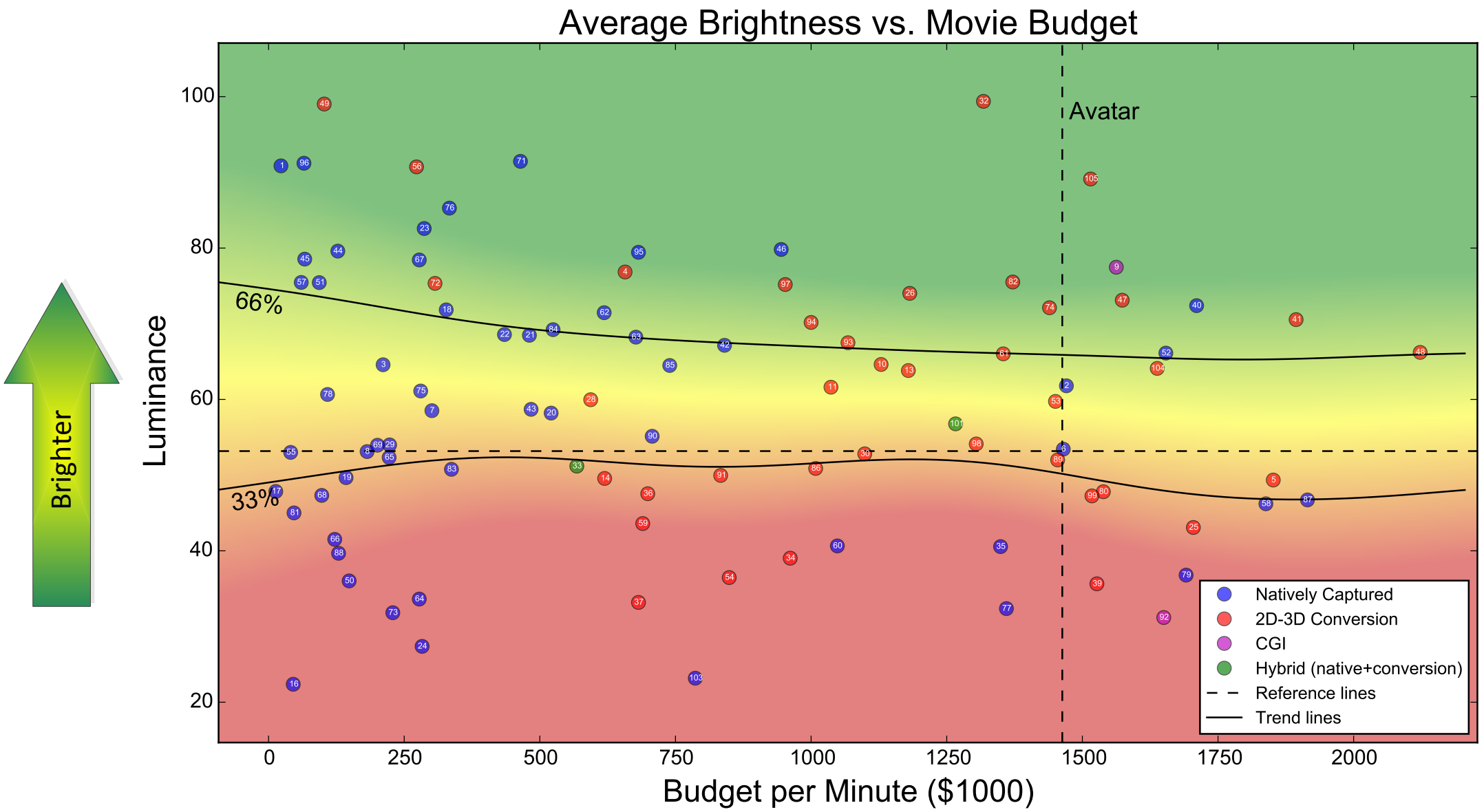


Figure 2.60: Diagram illustrating average brightness value relative to movie budget (per minute)

Natively Captured

1: 3-D Sex and Zen: Extreme Ecstasy ($22K/min)
2: 47 Ronin ($1470K/min)
3: A Very Harold & Kumar 3D Christmas ($211K/min)
6: Avatar ($1462K/min)
7: Bait ($301K/min)
8: Battle of the Year ($181K/min)
12: Cirque du Soleil: Journey of Man ($n/a K/min)
15: Creature from the Black Lagoon ($n/a K/min)
16: Dark Country ($45K/min)
17: Dial M for Murder ($13K/min)
18: Dolphin Tale ($327K/min)
19: Dolphins and Whales 3D: Tribes of the Ocean ($142K/min)
20: Dredd ($520K/min)
21: Drive Angry ($480K/min)
22: Final Destination 5 ($434K/min)
23: Flying Swords of Dragon Gate ($286K/min)
24: Fright Night ($283K/min)
27: Galapagos: The Enchanted Voyage ($n/a K/min)
29: Ghosts of the Abyss ($213K/min)
35: Hugo ($1349K/min)
38: Into the Deep ($n/a K/min)
40: Jack the Giant Slayer ($1710K/min)
42: Journey 2: The Mysterious Island ($840K/min)
43: Journey to the Center of the Earth ($483K/min)
44: Katy Perry: Part of Me ($127K/min)
45: Legends of Flight ($66K/min)
46: Life of Pi ($944K/min)
50: My Bloody Valentine ($148K/min)
51: One Direction: This Is Us ($93K/min)
52: Oz the Great and Powerful ($1653K/min)
55: Pina ($40K/min)
57: Piranha 3DD ($60K/min)
58: Pirates of the Caribbean: On Stranger Tides ($1838K/min)
60: Prometheus ($1048K/min)
62: Resident Evil: Afterlife ($618K/min)
63: Resident Evil: Retribution ($677K/min)
64: Sanctum ($277K/min)
65: Saw 3D: The Final Chapter ($222K/min)
66: Sea Rex 3D: Journey to a Prehistoric World ($121K/min)
67: Shark Night 3D ($277K/min)
68: Sharks 3D ($98K/min)
69: Silent Hill: Revelation 3D ($210K/min)
70: Space Station 3D ($n/a K/min)
71: Spy Kids 3-D: Game Over ($464K/min)
73: Stalingrad ($229K/min)
75: Step Up 3D ($280K/min)
76: Step Up Revolution ($333K/min)
77: TRON: Legacy ($1360K/min)
78: Texas Chainsaw 3D ($108K/min)
79: The Amazing Spider-Man ($1691K/min)
81: The Child's Eye ($46K/min)
83: The Darkest Hour ($337K/min)
84: The Final Destination ($524K/min)
85: The Great Gatsby ($739K/min)
87: The Hobbit: An Unexpected Journey ($1914K/min)
88: The Hole ($129K/min)
90: The Legend of Hercules ($707K/min)
95: The Three Musketeers ($681K/min)
96: The Ultimate Wave Tahiti ($65K/min)
102: Ultimate G's ($n/a K/min)
103: Underworld: Awakening ($786K/min)

Hybrid (Native+Conversion)

33: Hansel & Gretel: Witch Hunters ($568K/min)
101: Transformers: Dark of the Moon ($1266K/min)

2D-3D Conversion

4: Abraham Lincoln: Vampire Hunter ($657K/min)
5: Alice in Wonderland ($1851K/min)
10: Captain America: The First Avenger ($1129K/min)
11: Cats & Dogs: The Revenge of Kitty Galore ($1036K/min)
13: Clash of the Titans ($1179K/min)
14: Conan the Barbarian ($619K/min)
25: G-Force ($1704K/min)
26: G.I. Joe: Retaliation ($1181K/min)
28: Ghost Rider: Spirit of Vengeance ($593K/min)
30: Gravity ($1098K/min)
31: Green Lantern ($1769K/min)
32: Gulliver's Travels ($1317K/min)
34: Harry Potter and the Deathly Hallows: Part 2 ($961K/min)
36: I, Frankenstein ($698K/min)
37: Immortals ($681K/min)
39: Iron Man 3 ($1526K/min)
41: John Carter ($1893K/min)
47: Man of Steel ($1573K/min)
48: Men in Black 3 ($2122K/min)
49: Mummies: Secrets of the Pharaohs ($102K/min)
53: Pacific Rim ($1450K/min)
54: Percy Jackson: Sea of Monsters ($849K/min)
56: Piranha 3D ($272K/min)
59: Priest ($689K/min)
61: R.I.P.D. ($1354K/min)
72: Spy Kids: All the Time in the World in 4D ($306K/min)
74: Star Trek Into Darkness ($1439K/min)
80: The Avengers ($1538K/min)
82: The Chronicles of Narnia: The Voyage of the Dawn Treader ($1371K/min)
86: The Green Hornet ($1008K/min)
89: The Last Airbender ($1456K/min)
91: The Nutcracker in 3D ($833K/min)
93: The Smurfs ($1067K/min)
94: The Smurfs 2 ($1000K/min)
97: The Wolverine ($952K/min)
98: Thor ($1304K/min)
99: Thor: The Dark World ($1517K/min)
100: Titanic ($n/a K/min)
104: World War Z ($1637K/min)
105: Wrath of the Titans ($1515K/min)

CGI

9: Bolt ($1562K/min)
92: The Polar Express ($1650K/min)

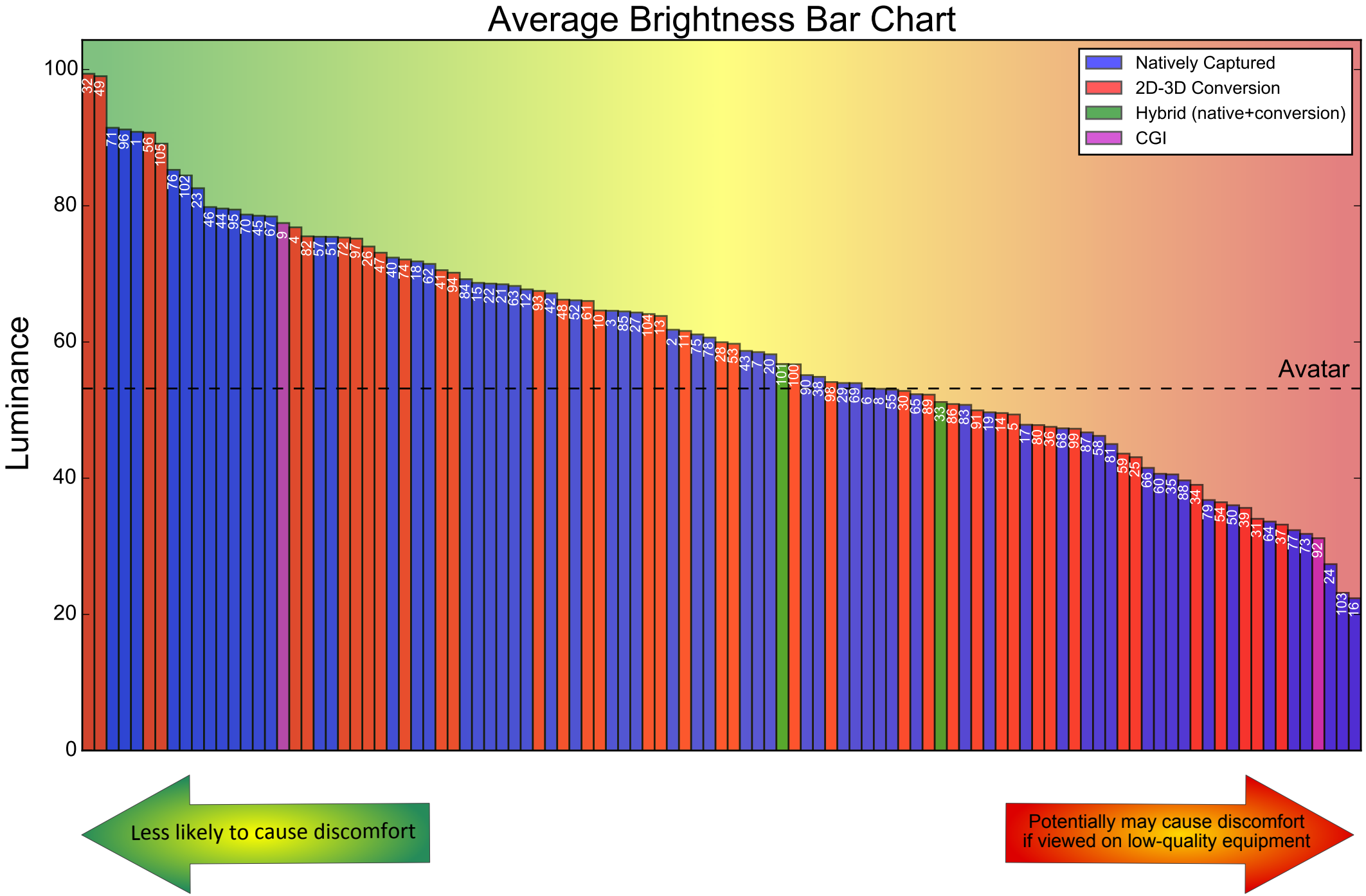


Figure 2.61: Bar chart with movies sorted by average brightness value in descending order

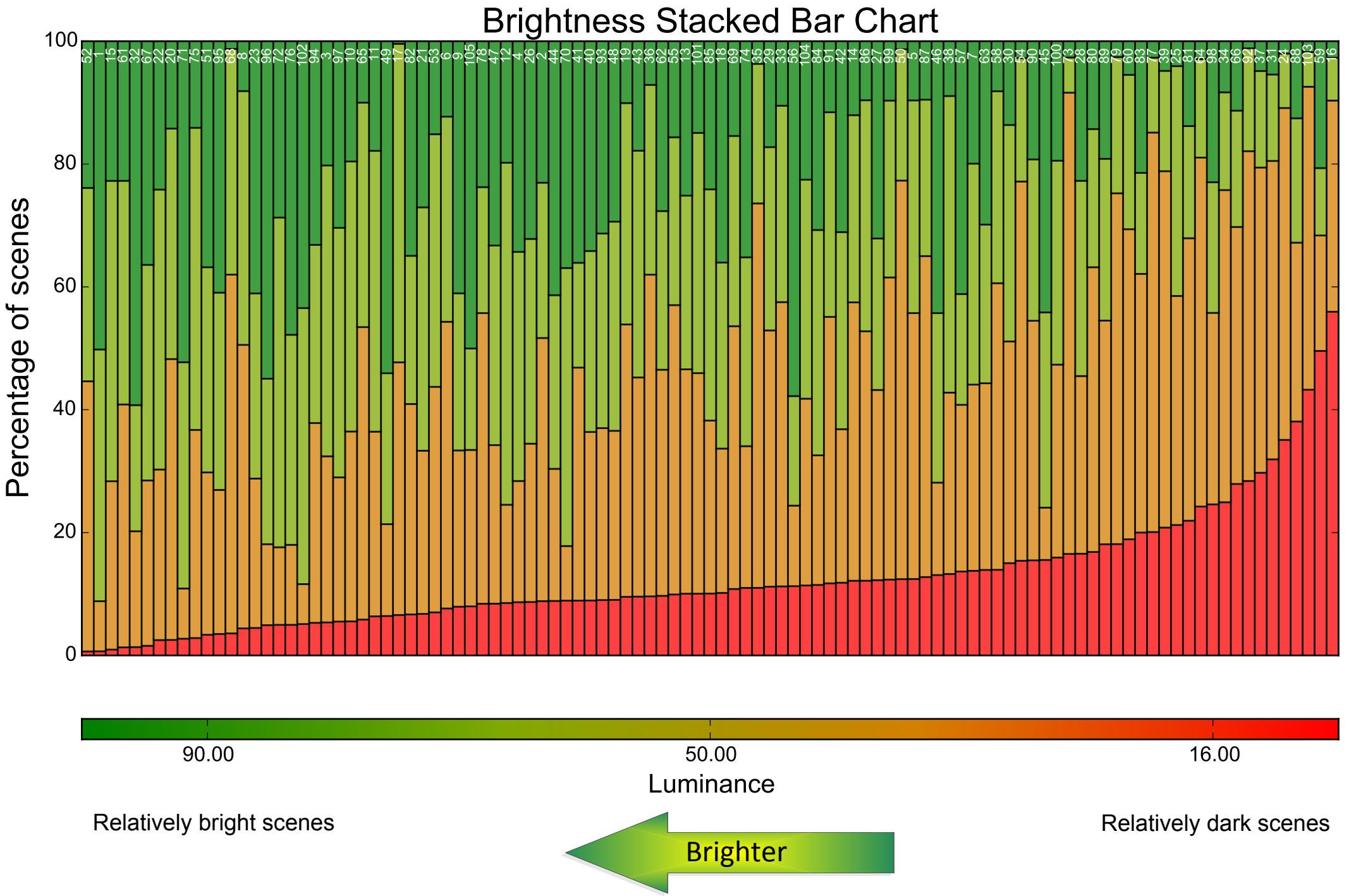


Figure 2.62: Stacked bar chart with movies sorted by the amount of relatively dark scenes

Chapter 3

Movie Ratings

Next we present movie ratings in several categories. For each metric we include the following categories:

- Three budget ranges (low-budget, mid-budget and high-budget movies)
- Four release-date ranges
- One overall category
- Two trade-off categories — one for movie budget and one for release date

In this section we exclude metrics for which the proper movie ranking is arguable or unclear: depth budget, depth continuity, temporal shift, channel mismatch, crosstalk and average brightness. Depending on the metric, we may include additional categories for natively captured films only. Most categories rank movies in a straightforward way. For the trade-off categories we rank them on the basis of proximity to the optimum point (Figure 3.1 shows an example).

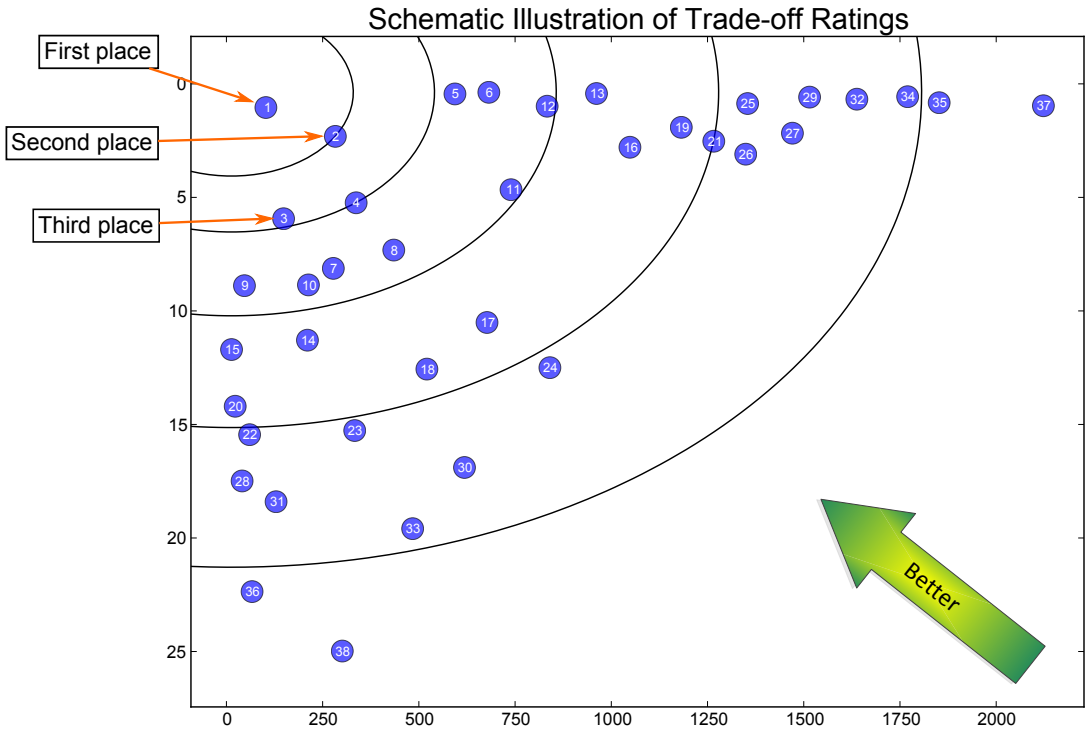


Figure 3.1: Schematic illustration of how movies are ranked in the trade-off categories. The points are numbered correspondingly

The section concludes with the same set of categories, but it combines all relevant metrics (vertical parallax, scale/rotation mismatch, color mismatch and sharpness mismatch). Ratings in these categories are based on the average rank for the corresponding categories of different metrics.

3.1 Vertical Parallax

3.1.1 Budget Categories

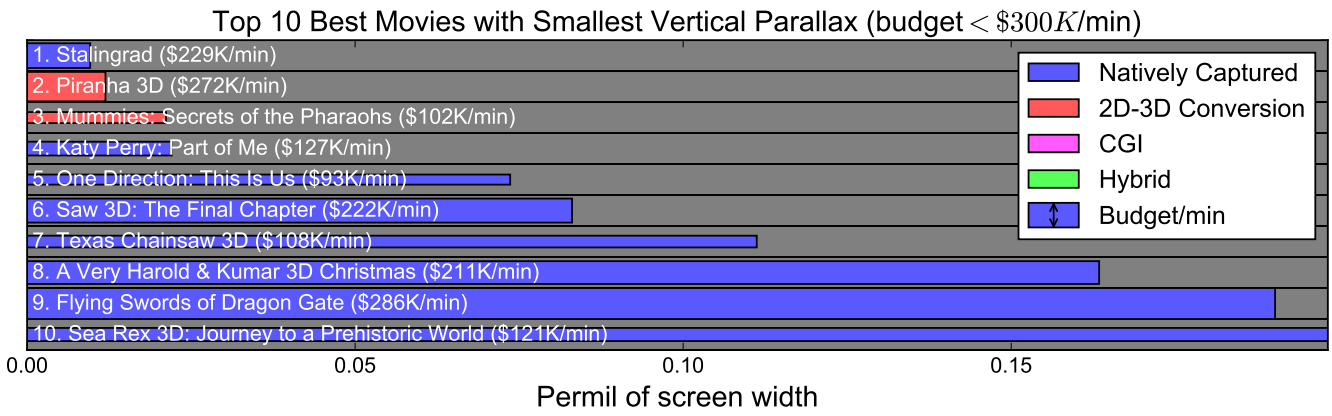


Figure 3.2: Diagram with top 10 best movies in terms of vertical parallax with budgets less than \$300K/minute

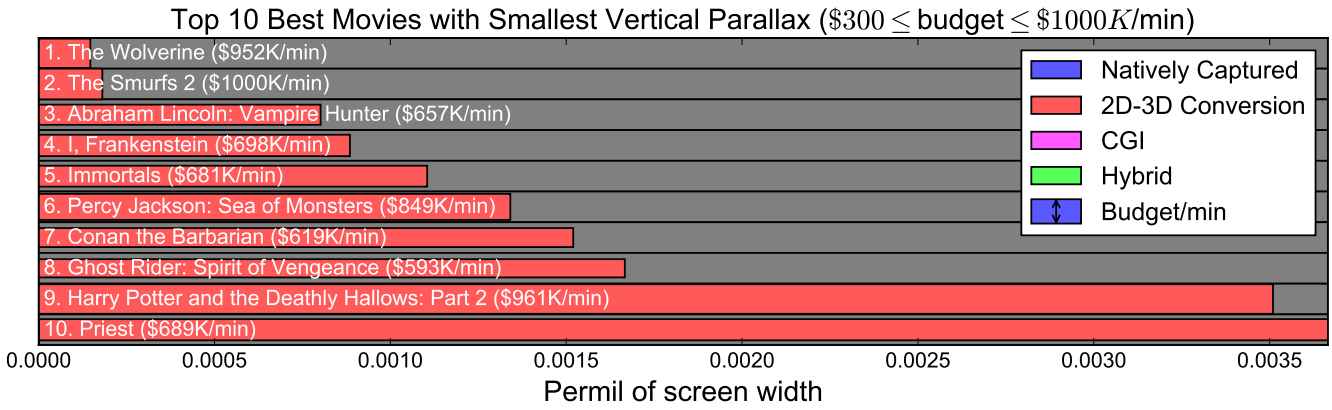


Figure 3.3: Diagram with top 10 best movies in terms of vertical parallax with budgets less than \$1000K/minute and more than \$300K/minute

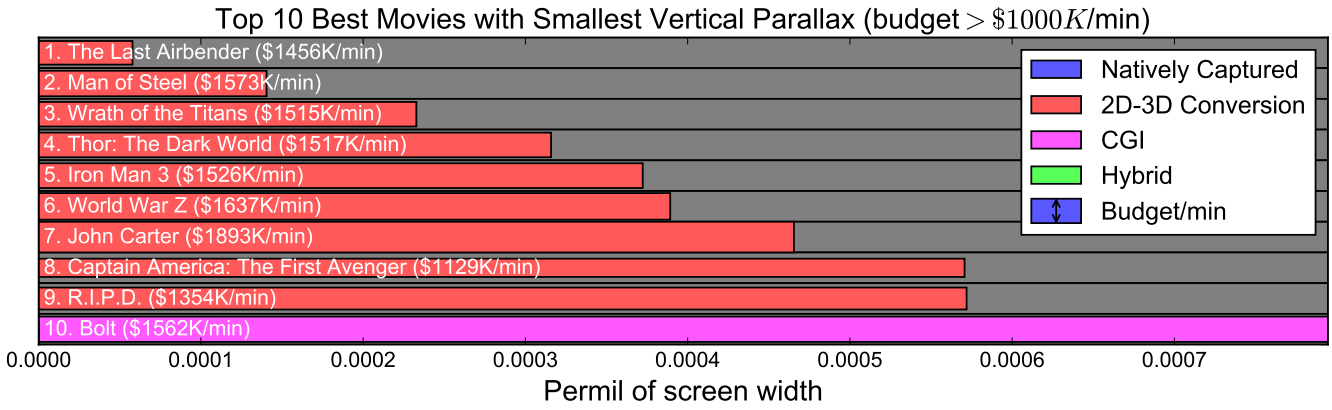


Figure 3.4: Diagram with top 10 best movies in terms of vertical parallax with budgets more than \$1000K/minute

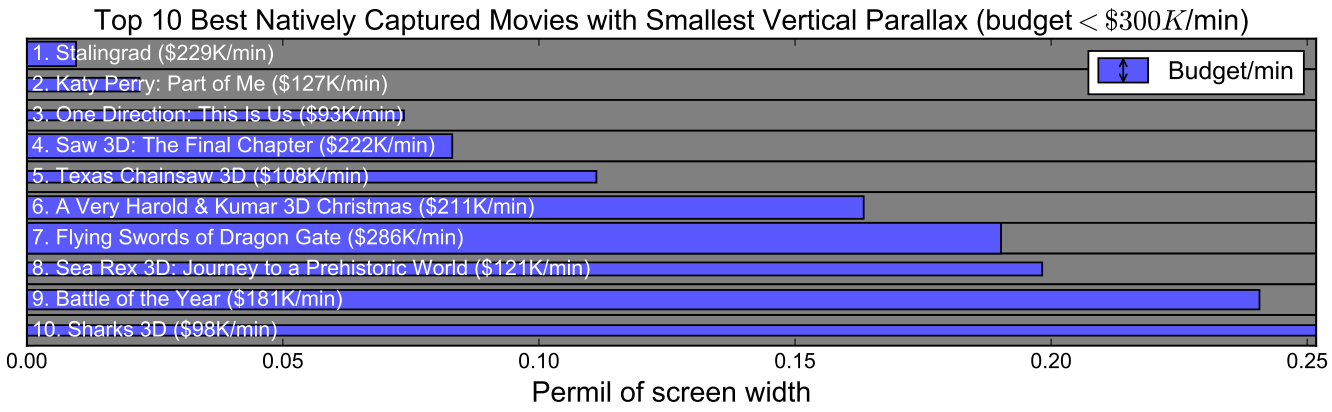


Figure 3.5: Diagram with top 10 best natively captured movies in terms of vertical parallax with budgets less than \$300K/minute

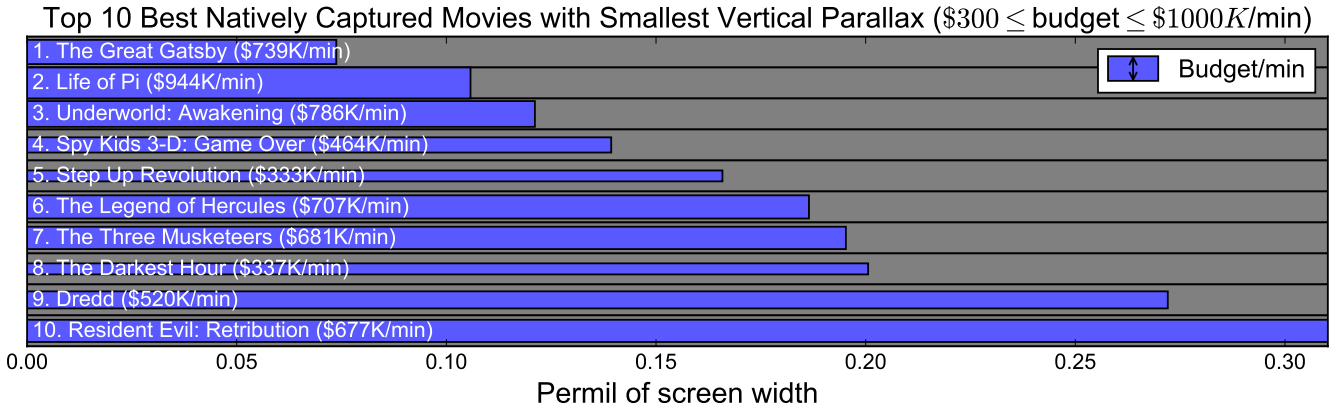


Figure 3.6: Diagram with top 10 best natively captured movies in terms of vertical parallax with budgets less than \$1000K/minute and more than \$300K/minute

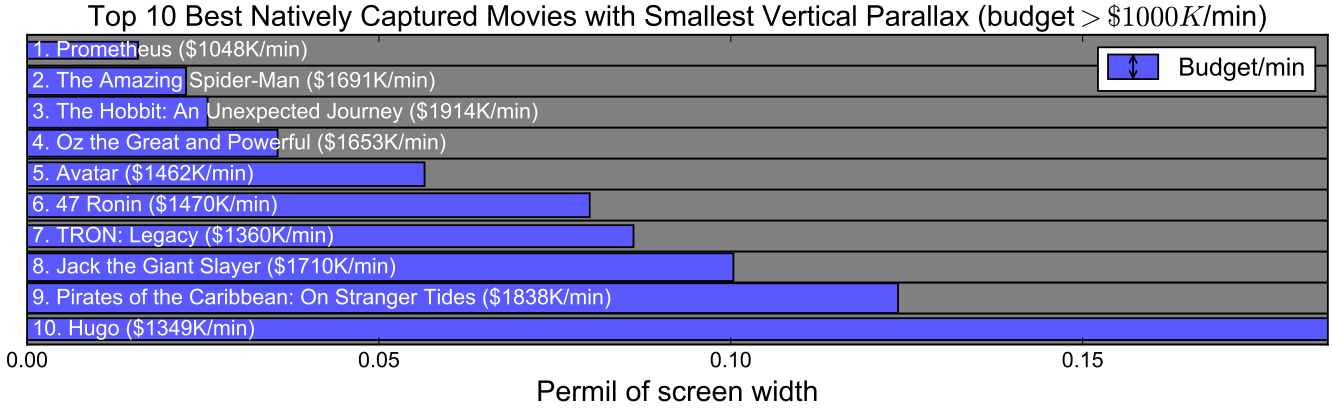


Figure 3.7: Diagram with top 10 best natively captured movies in terms of vertical parallax with budgets more than \$1000K/minute

3.1.2 Release Date Categories

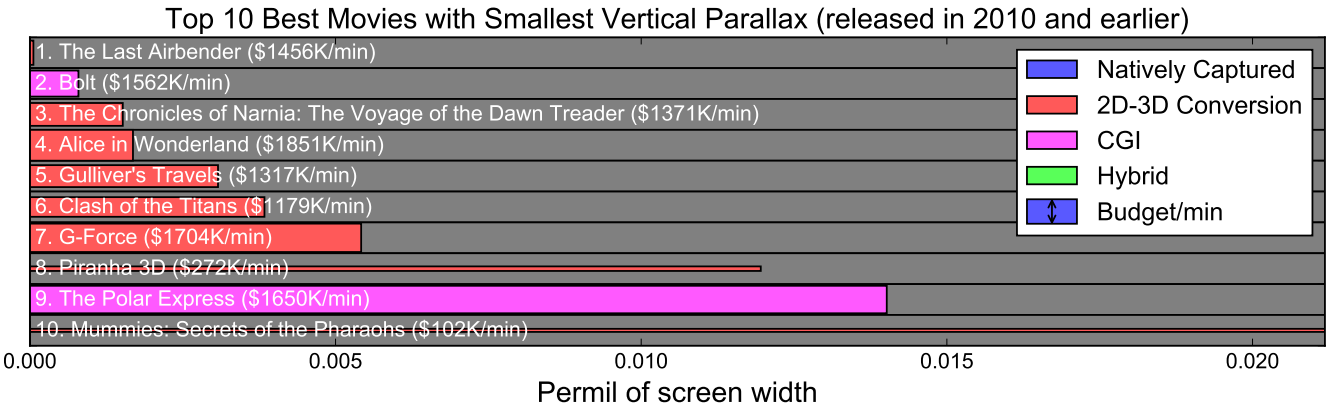


Figure 3.8: Diagram with top 10 best movies in terms of vertical parallax released in 2010 and earlier

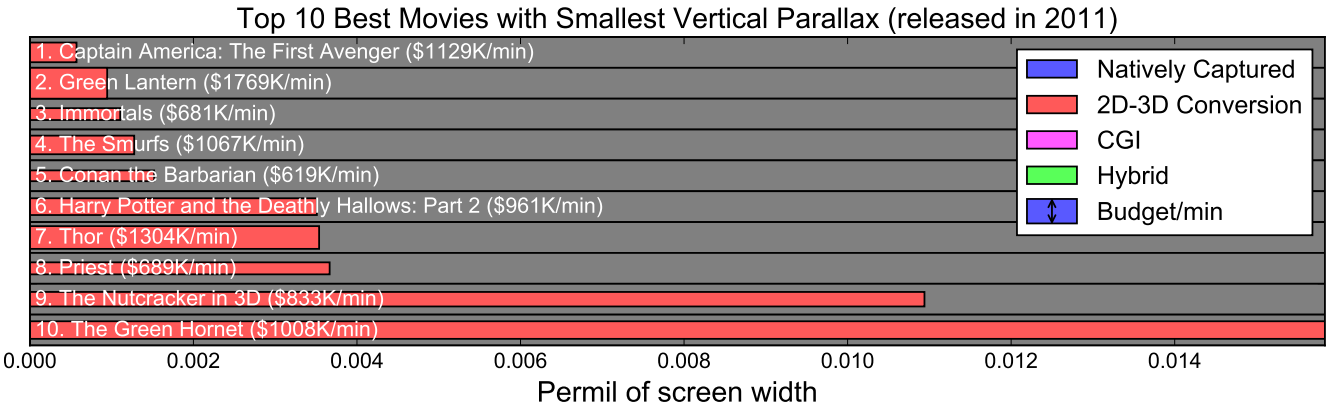


Figure 3.9: Diagram with top 10 best movies in terms of vertical parallax released in 2011

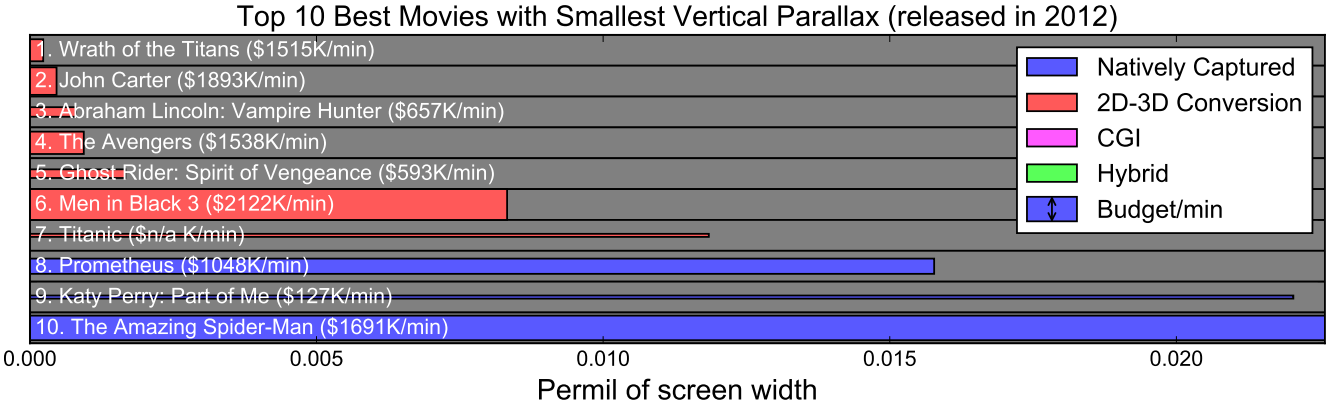


Figure 3.10: Diagram with top 10 best movies in terms of vertical parallax released in 2012

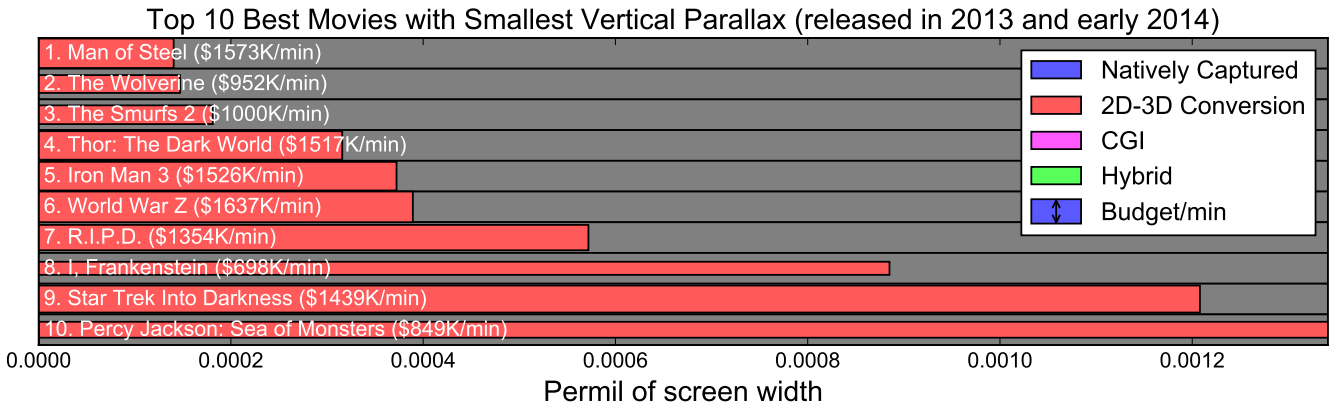


Figure 3.11: Diagram with top 10 best movies in terms of vertical parallax released in 2013 and early 2014

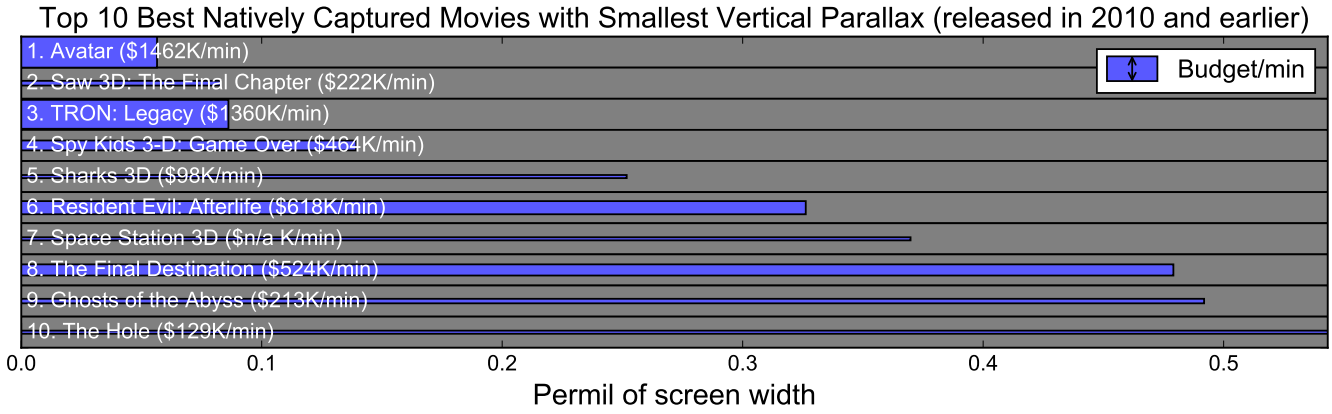


Figure 3.12: Diagram with top 10 best natively captured movies in terms of vertical parallax released in 2010 and earlier

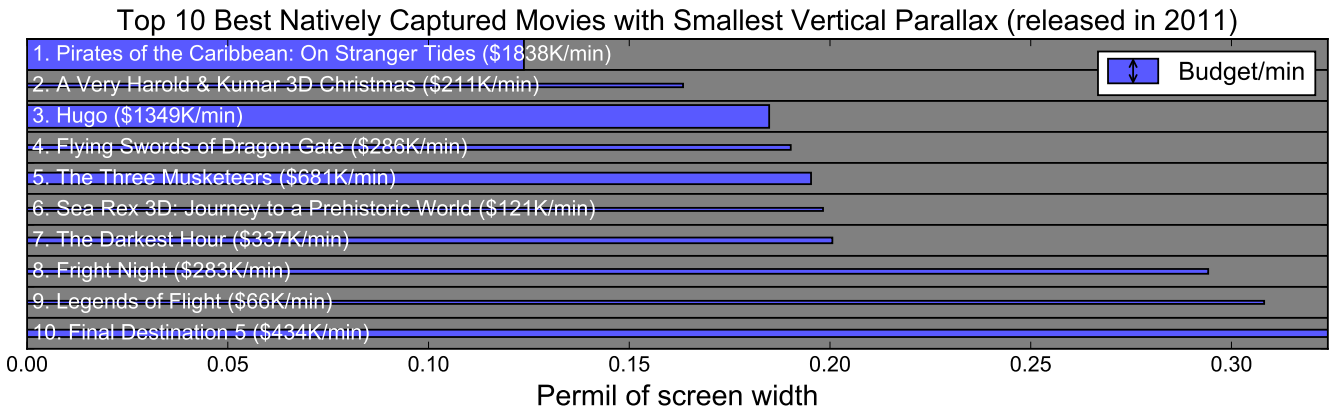


Figure 3.13: Diagram with top 10 best natively captured movies in terms of vertical parallax released in 2011

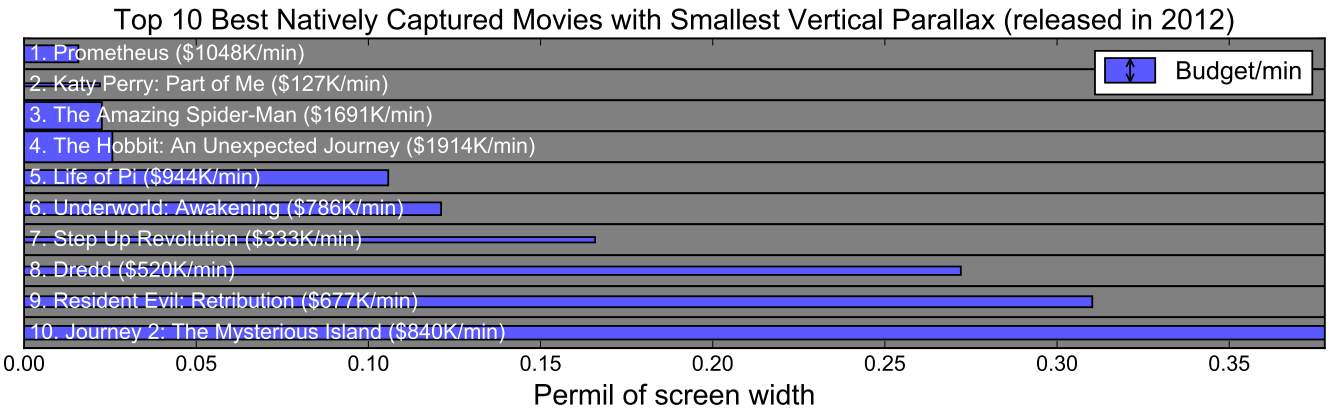


Figure 3.14: Diagram with top 10 best natively captured movies in terms of vertical parallax released in 2012

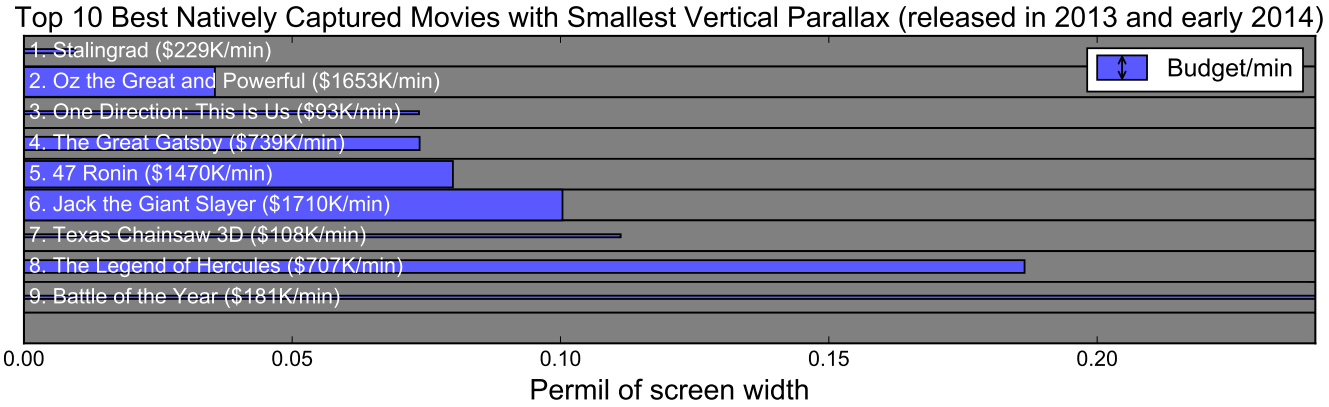


Figure 3.15: Diagram with top 10 best natively captured movies in terms of vertical parallax released in 2013 and early 2014

3.1.3 Overall Categories

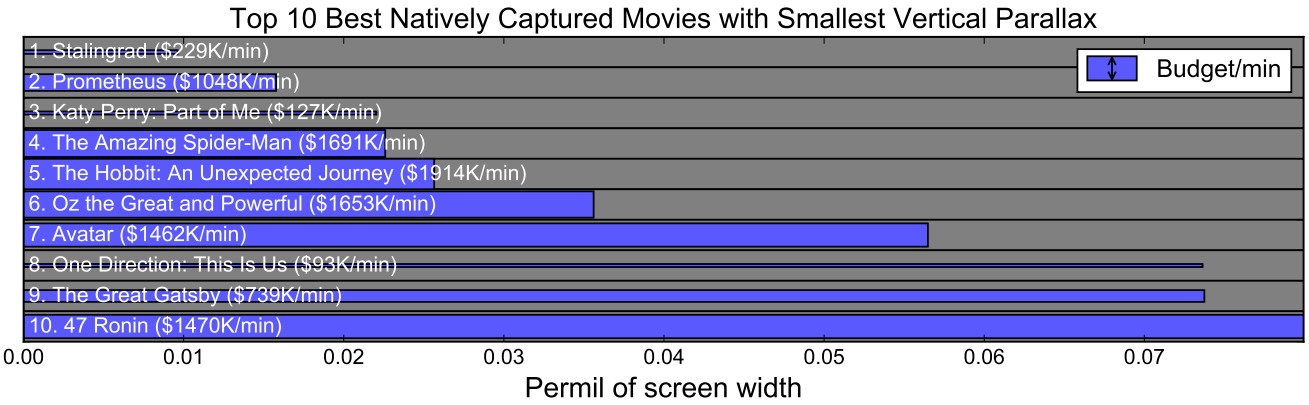


Figure 3.16: Diagram with top 10 best natively captured movies in terms of vertical parallax

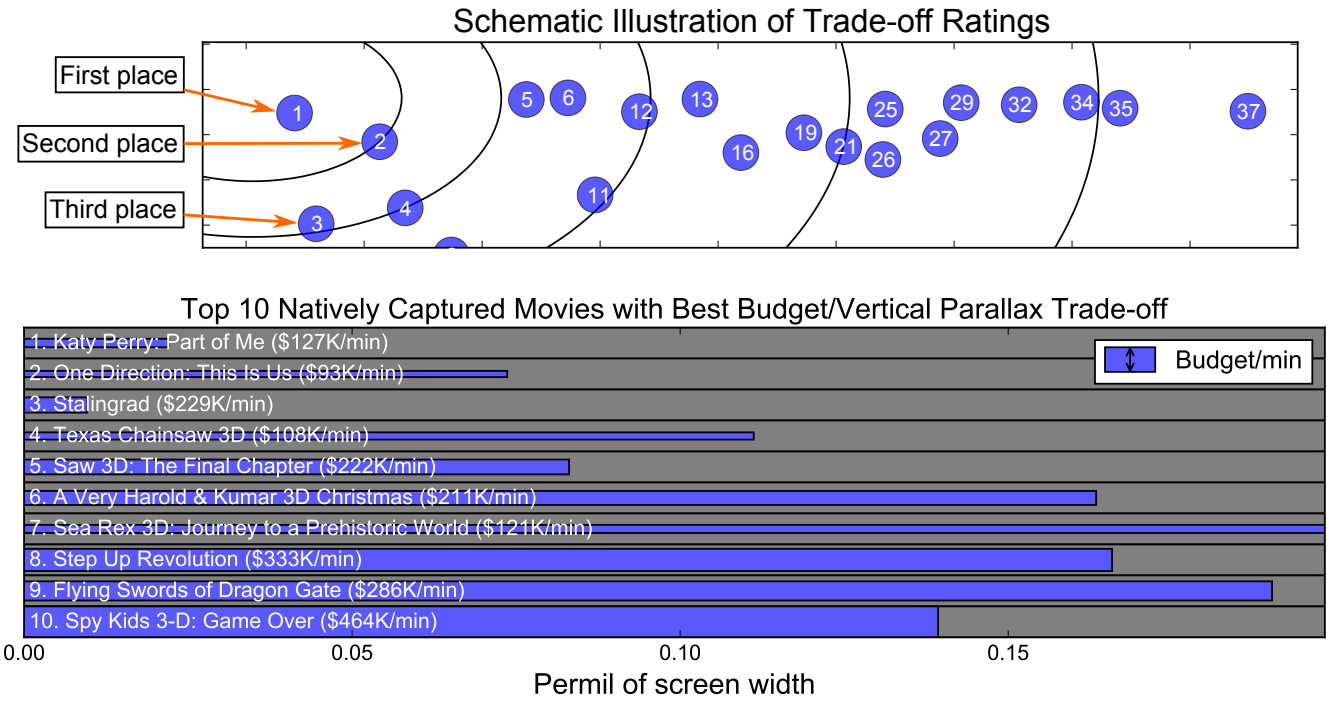


Figure 3.17: Diagram with top 10 best natively captured movies in terms of budget/vertical parallax trade-off

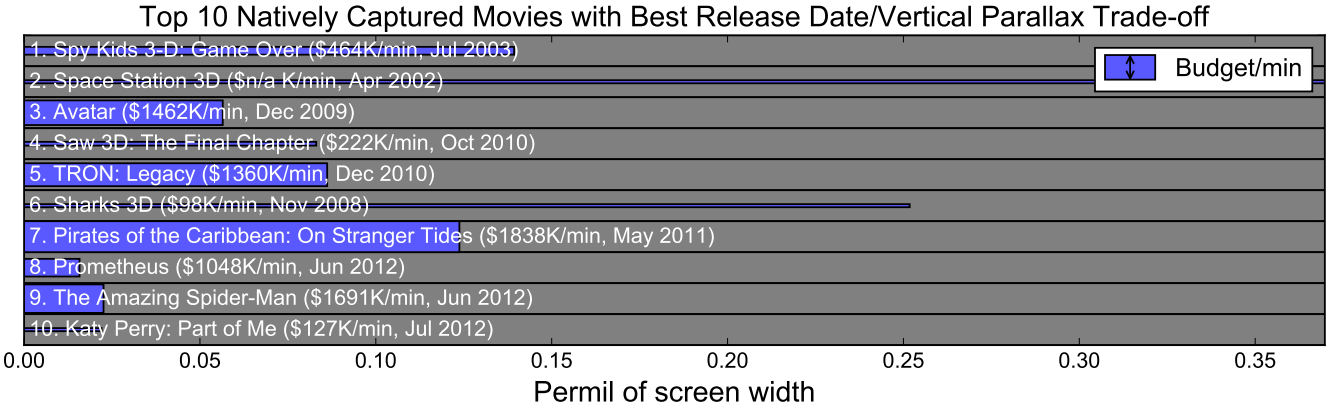


Figure 3.18: Diagram with top 10 best natively captured movies in terms of release date/vertical parallax trade-off

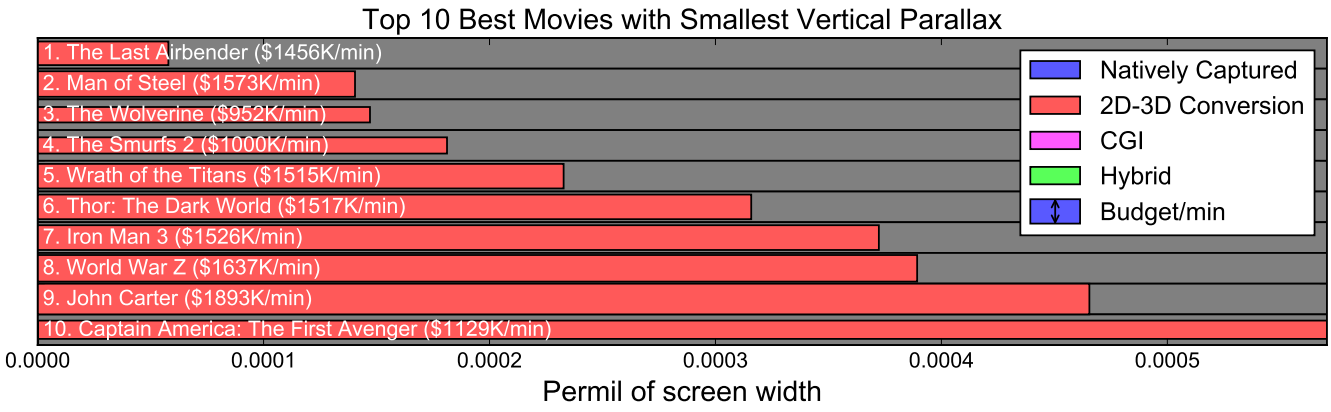


Figure 3.19: Diagram with top 10 best movies in terms of vertical parallax

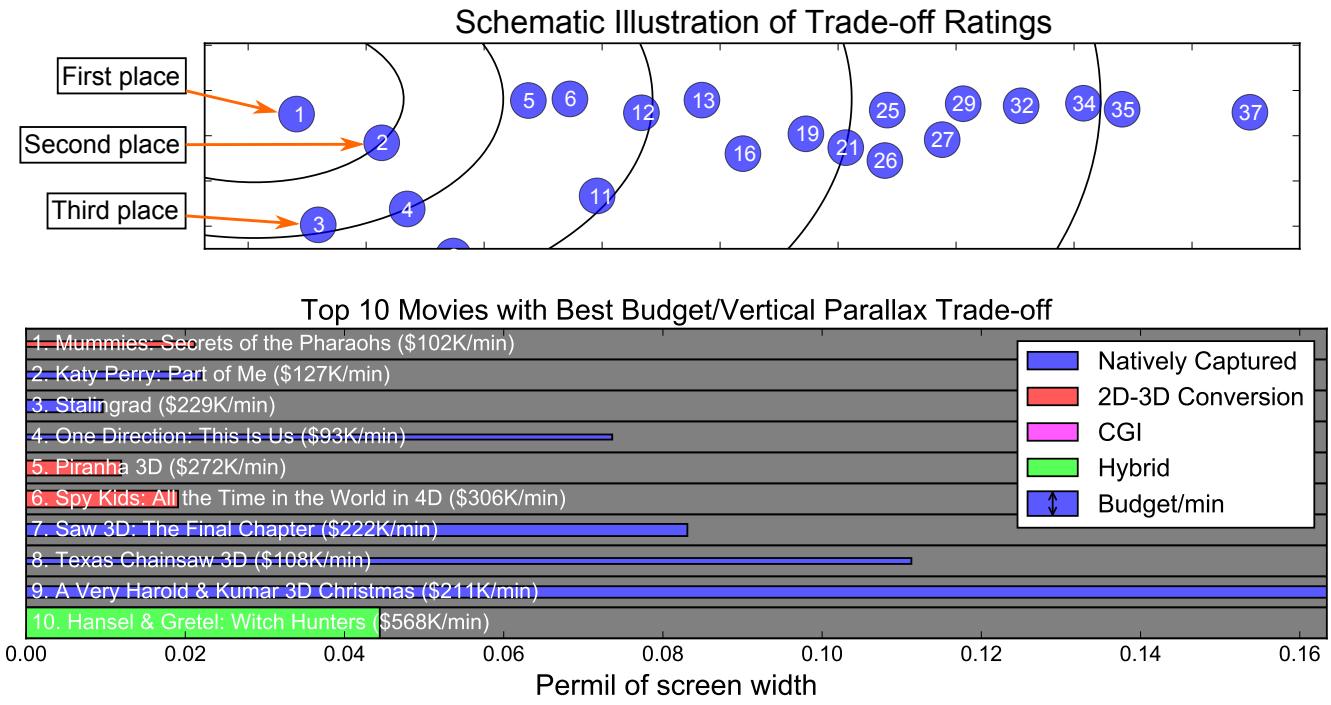


Figure 3.20: Diagram with top 10 best movies in terms of budget/vertical parallax trade-off

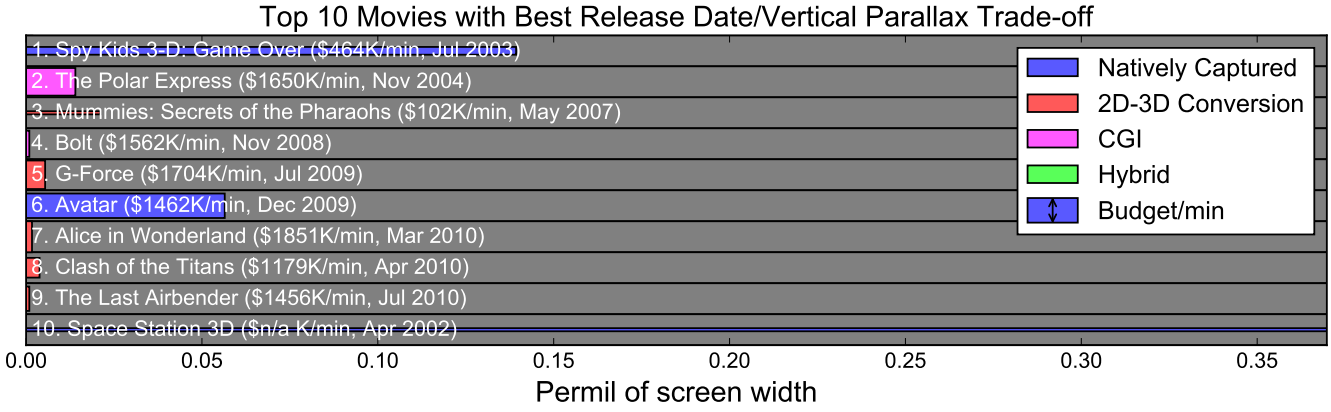


Figure 3.21: Diagram with top 10 best movies in terms of release date/vertical parallax trade-off

3.2 Scale Mismatch

3.2.1 Budget Categories

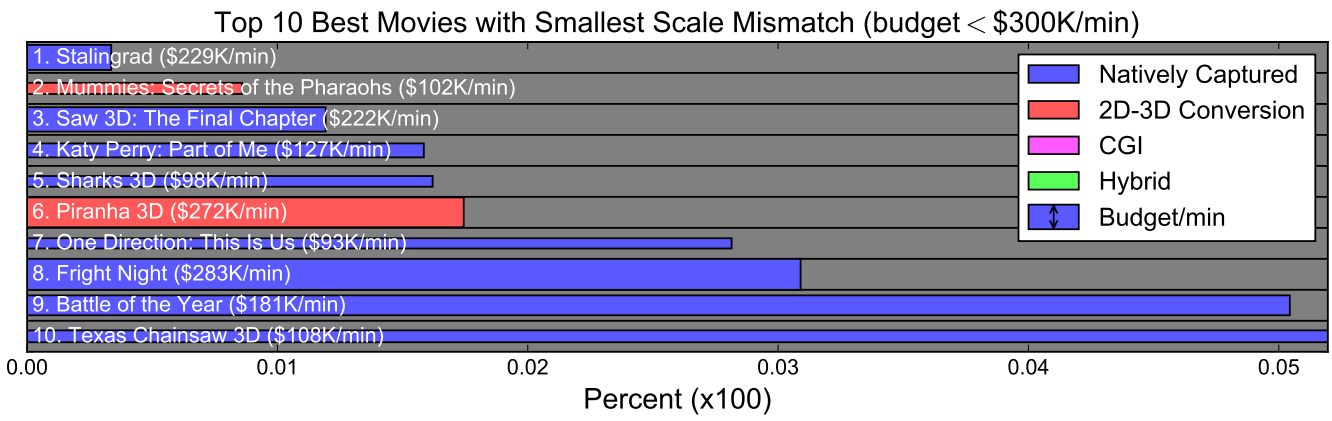


Figure 3.22: Diagram with top 10 best movies in terms of scale mismatch with budgets less than $300K/minute

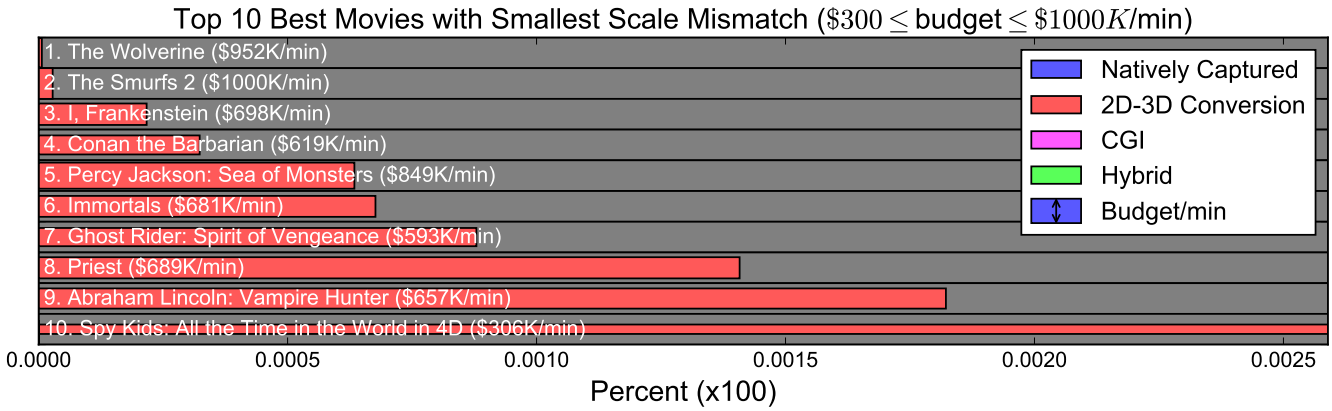


Figure 3.23: Diagram with top 10 best movies in terms of scale mismatch with budgets less than $1000K/minute and more than $300K/minute

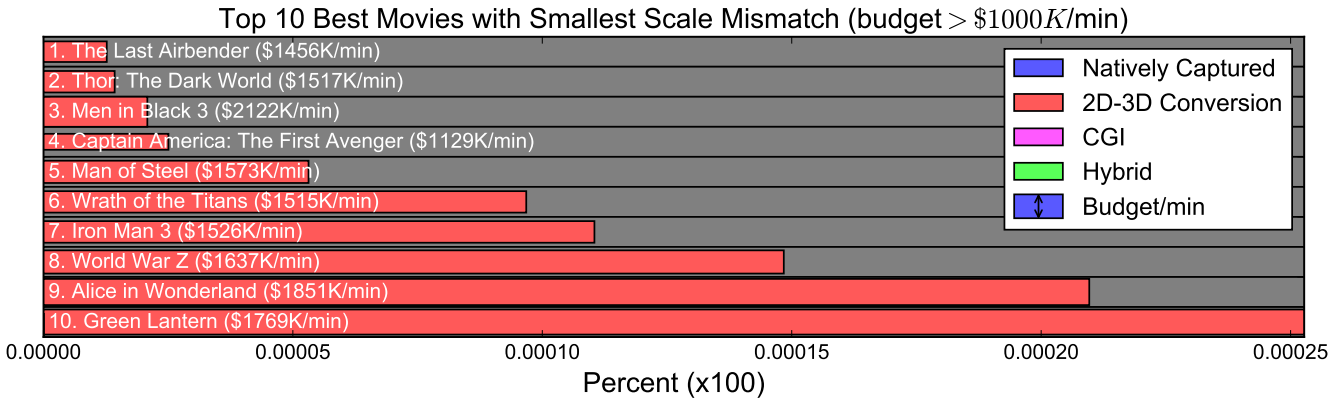


Figure 3.24: Diagram with top 10 best movies in terms of scale mismatch with budgets more than $1000K/minute

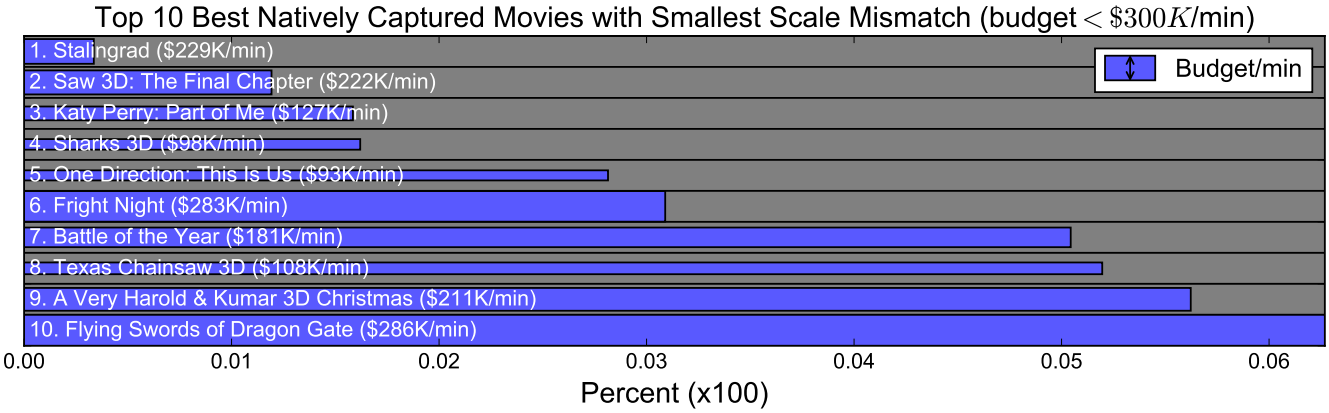


Figure 3.25: Diagram with top 10 best natively captured movies in terms of scale mismatch with budgets less than \$300K/minute

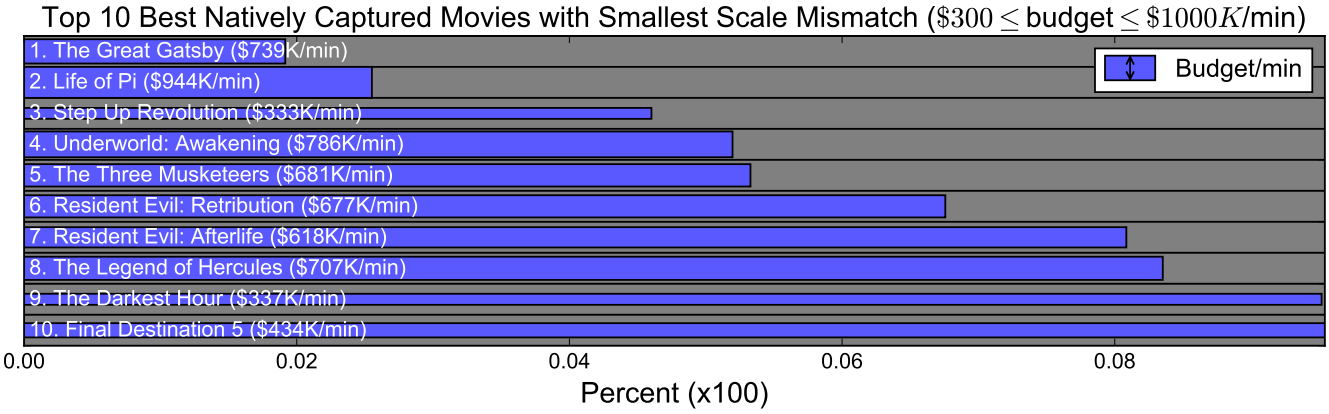


Figure 3.26: Diagram with top 10 best natively captured movies in terms of scale mismatch with budgets less than \$1000K/minute and more than \$300K/minute

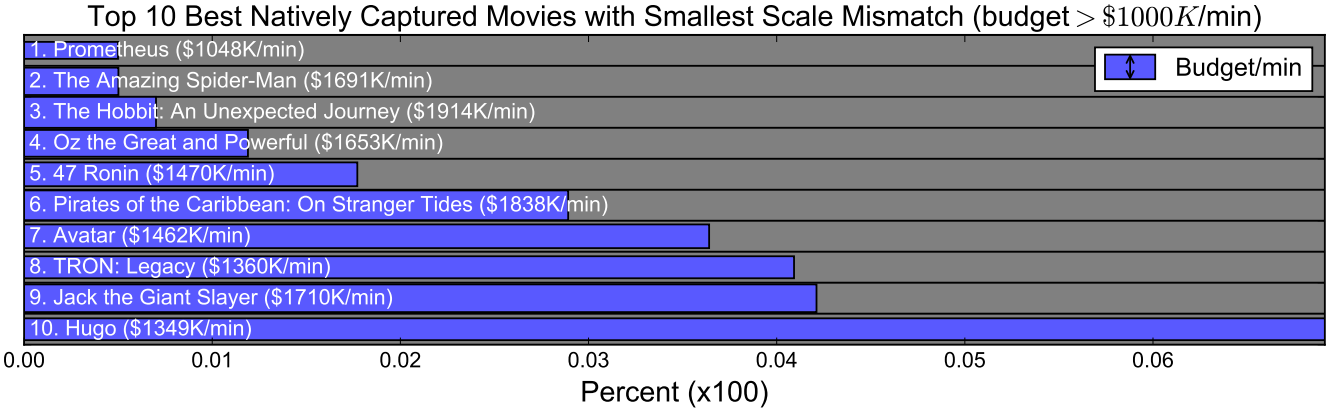


Figure 3.27: Diagram with top 10 best natively captured movies in terms of scale mismatch with budgets more than \$1000K/minute

3.2.2 Release Date Categories

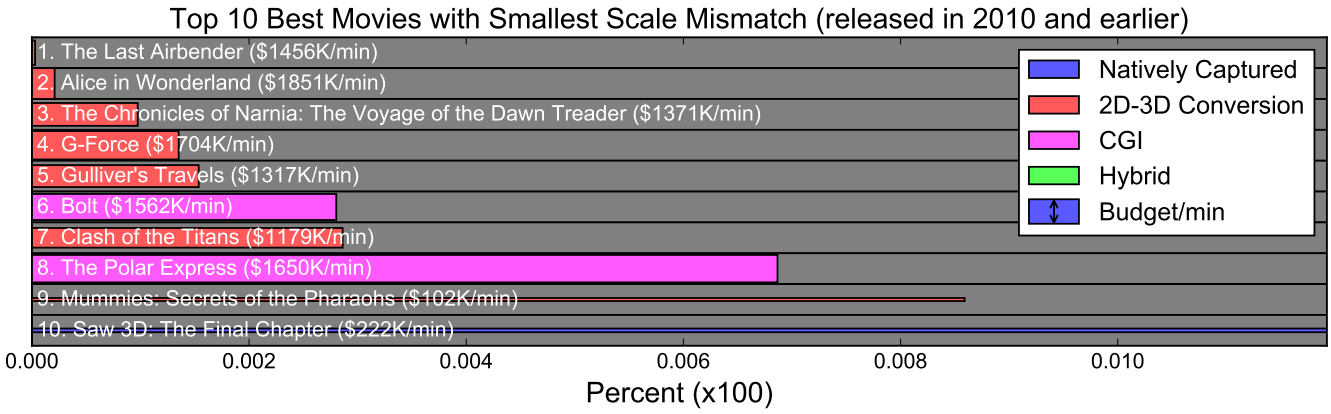


Figure 3.28: Diagram with top 10 best movies in terms of scale mismatch released in 2010 and earlier

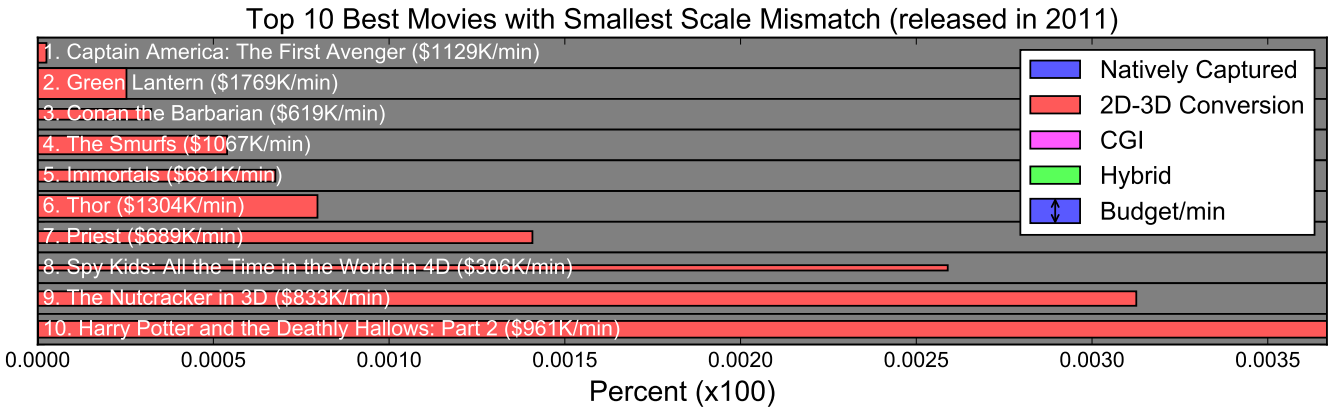


Figure 3.29: Diagram with top 10 best movies in terms of scale mismatch released in 2011

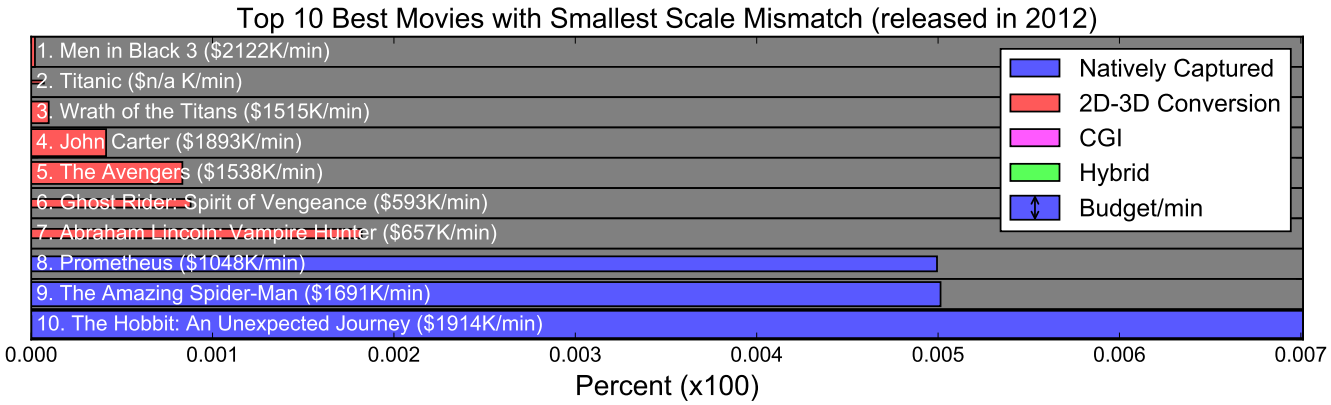


Figure 3.30: Diagram with top 10 best movies in terms of scale mismatch released in 2012

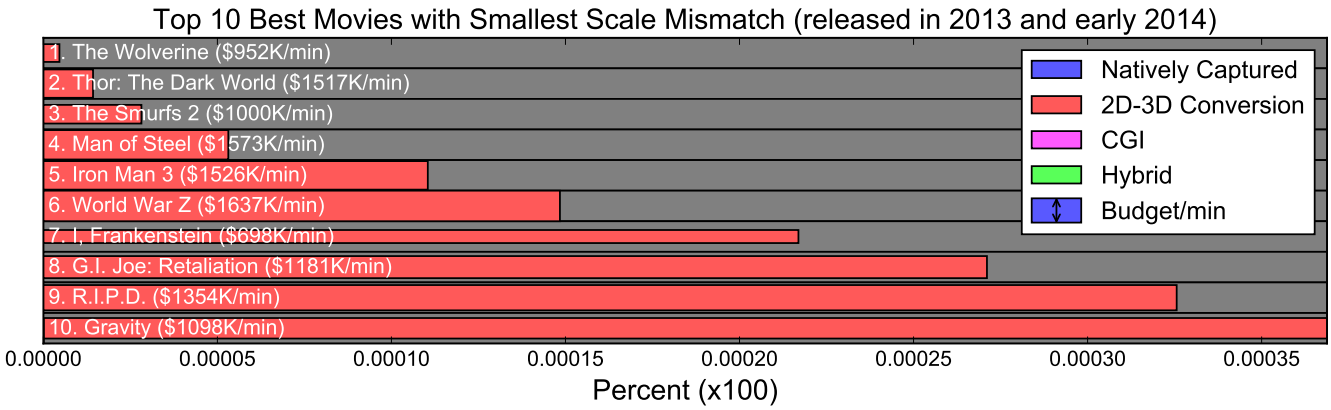


Figure 3.31: Diagram with top 10 best movies in terms of scale mismatch released in 2013 and early 2014

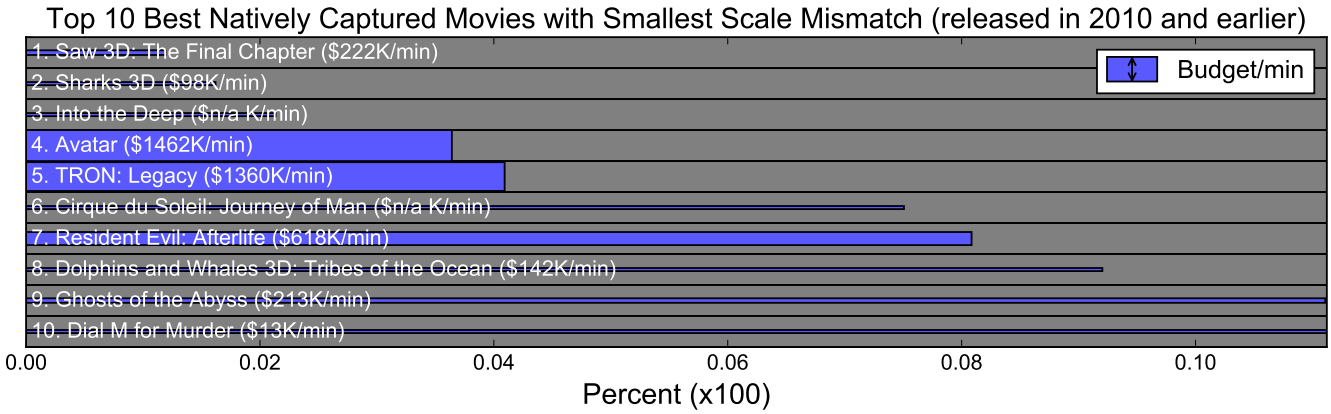


Figure 3.32: Diagram with top 10 best natively captured movies in terms of scale mismatch released in 2010 and earlier

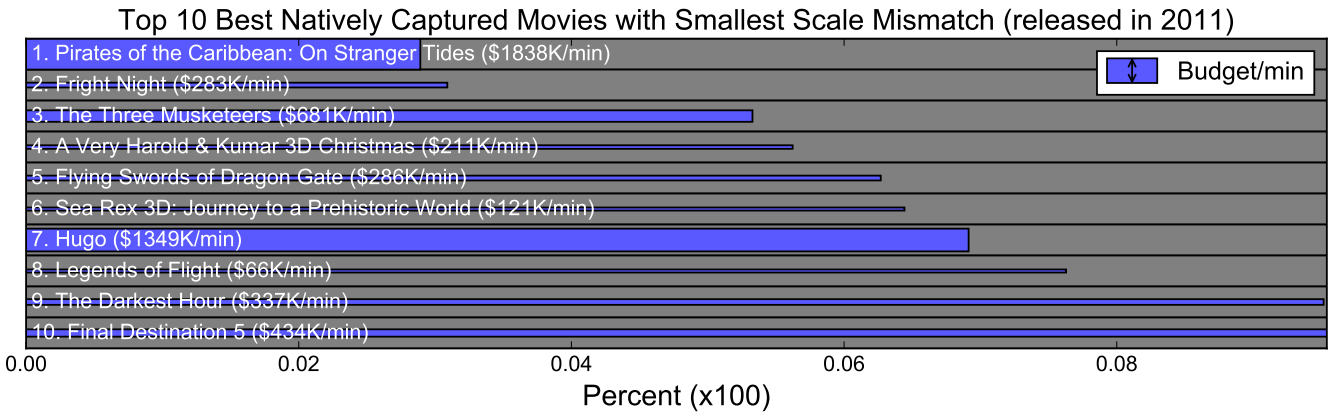


Figure 3.33: Diagram with top 10 best natively captured movies in terms of scale mismatch released in 2011

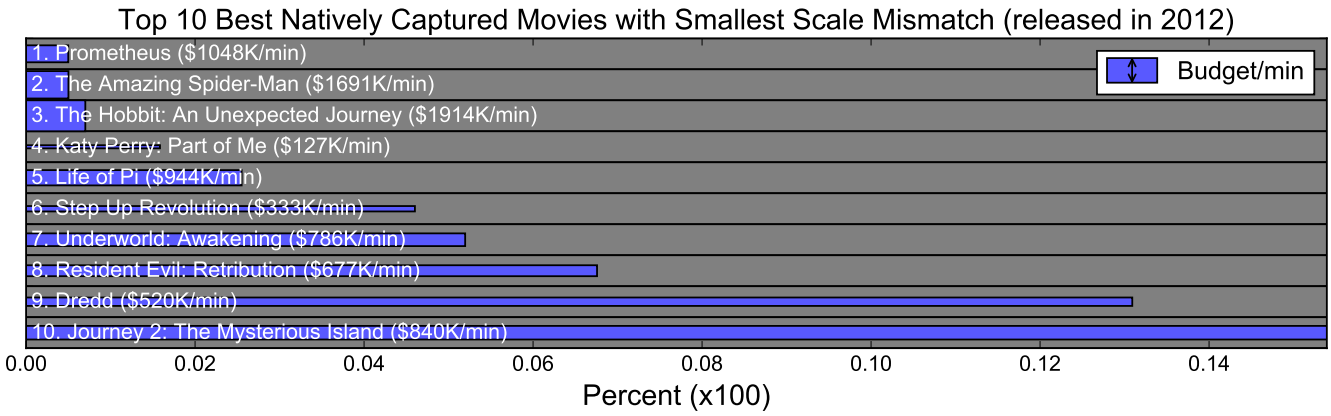


Figure 3.34: Diagram with top 10 best natively captured movies in terms of scale mismatch released in 2012

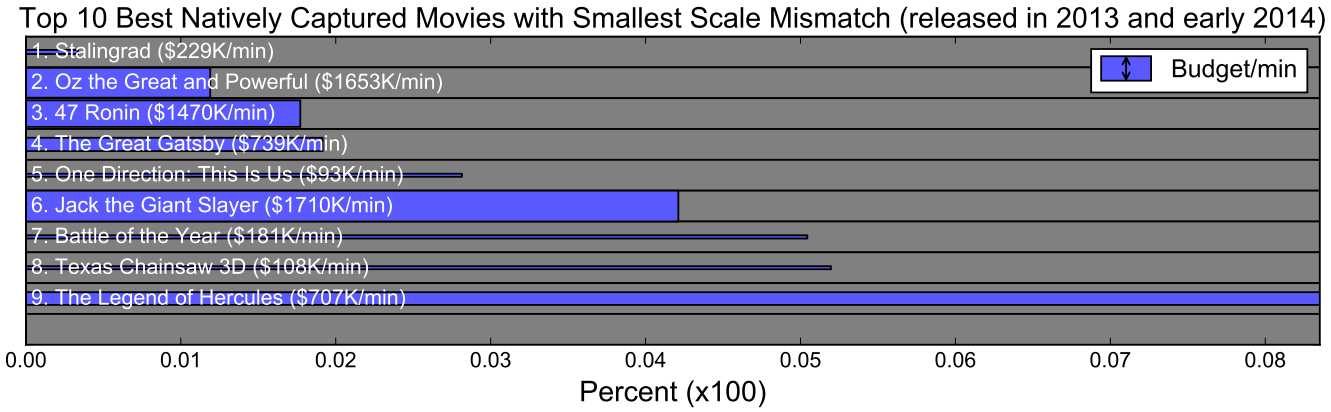


Figure 3.35: Diagram with top 10 best natively captured movies in terms of scale mismatch released in 2013 and early 2014

3.2.3 Overall Categories

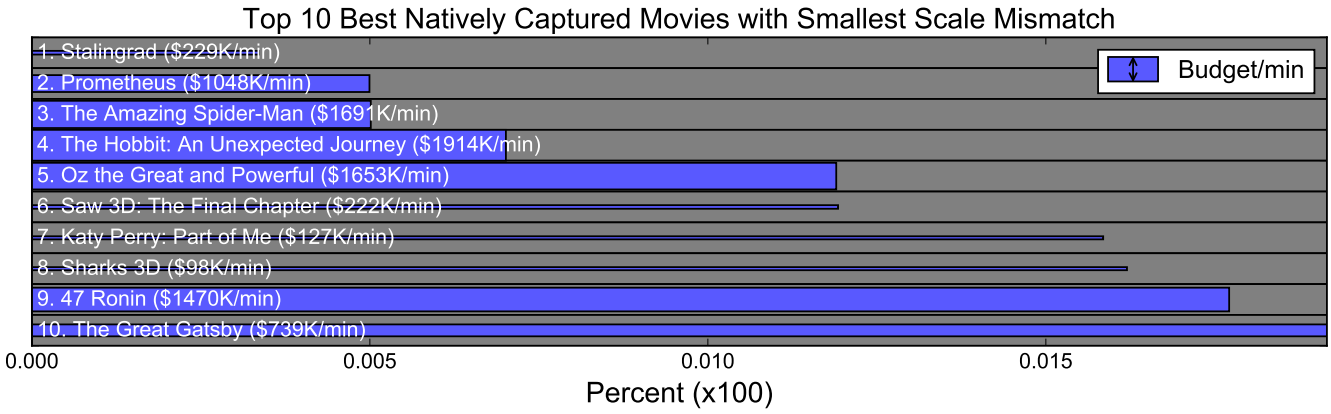


Figure 3.36: Diagram with top 10 best natively captured movies in terms of scale mismatch

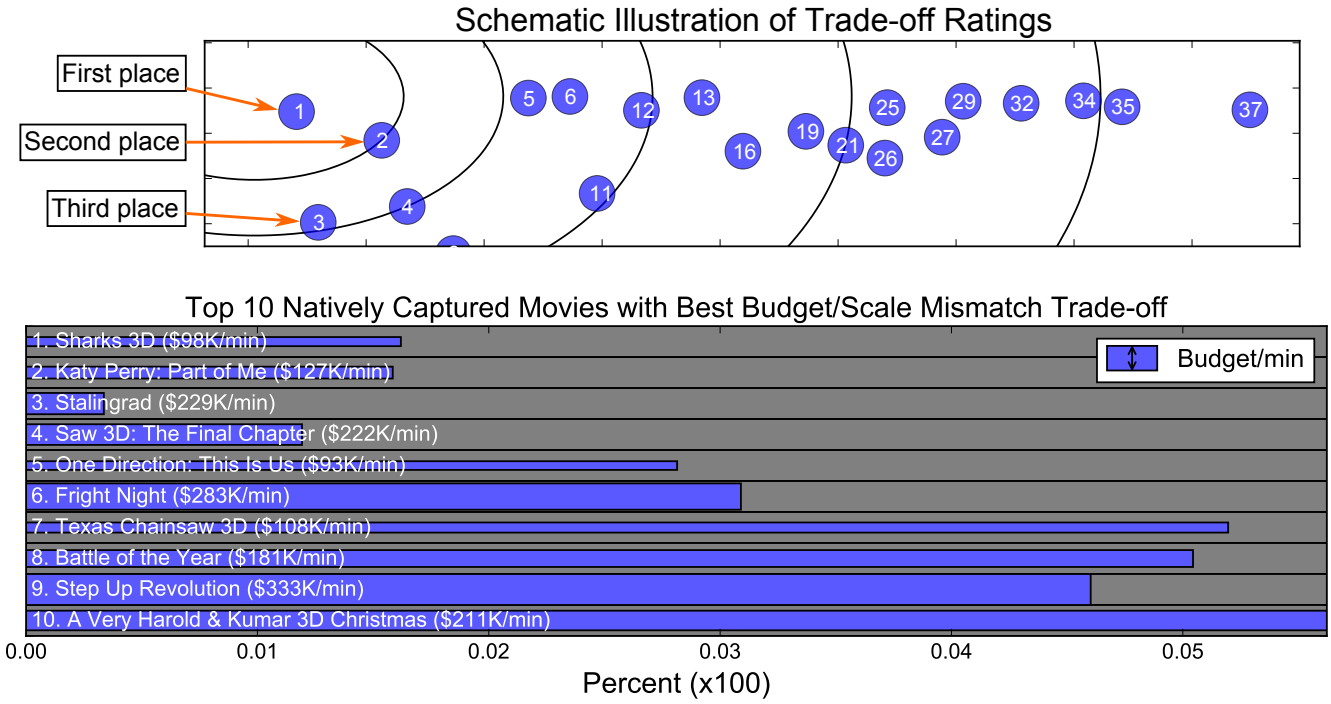


Figure 3.37: Diagram with top 10 best natively captured movies in terms of budget/scale mismatch trade-off

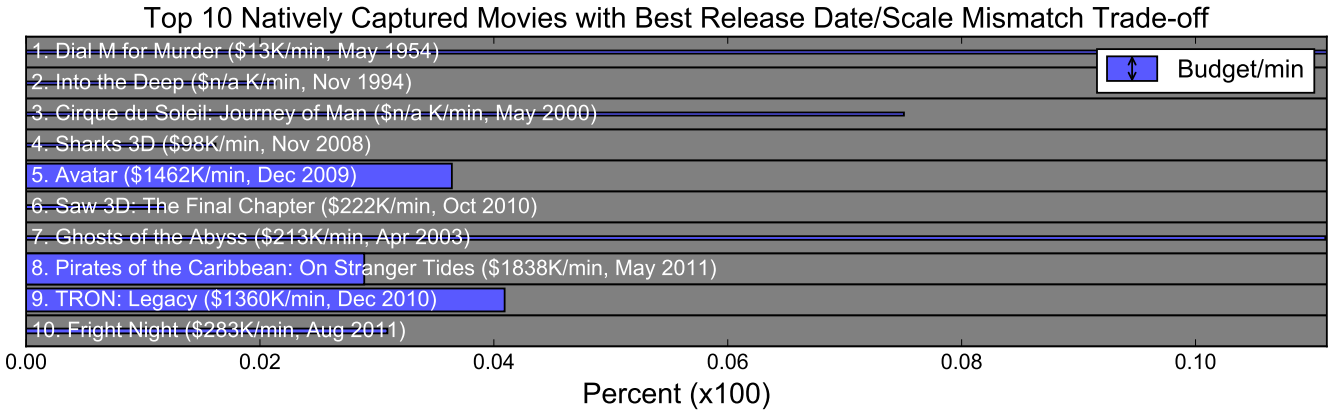


Figure 3.38: Diagram with top 10 best natively captured movies in terms of release date/scale mismatch trade-off

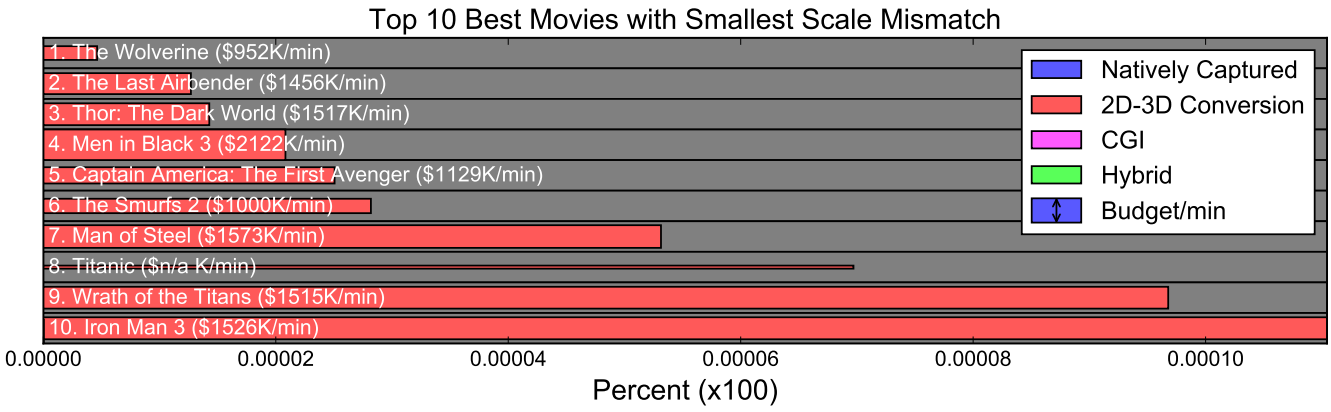


Figure 3.39: Diagram with top 10 best movies in terms of scale mismatch

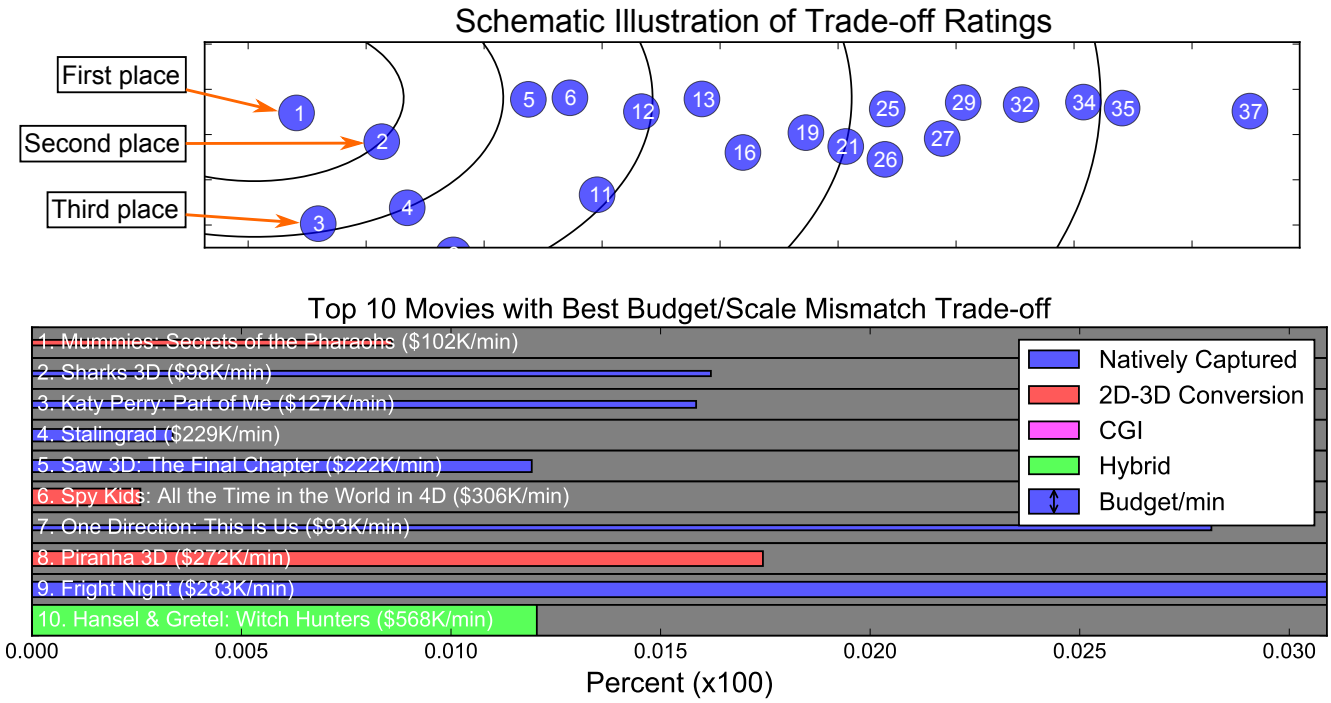


Figure 3.40: Diagram with top 10 best movies in terms of budget/scale mismatch trade-off

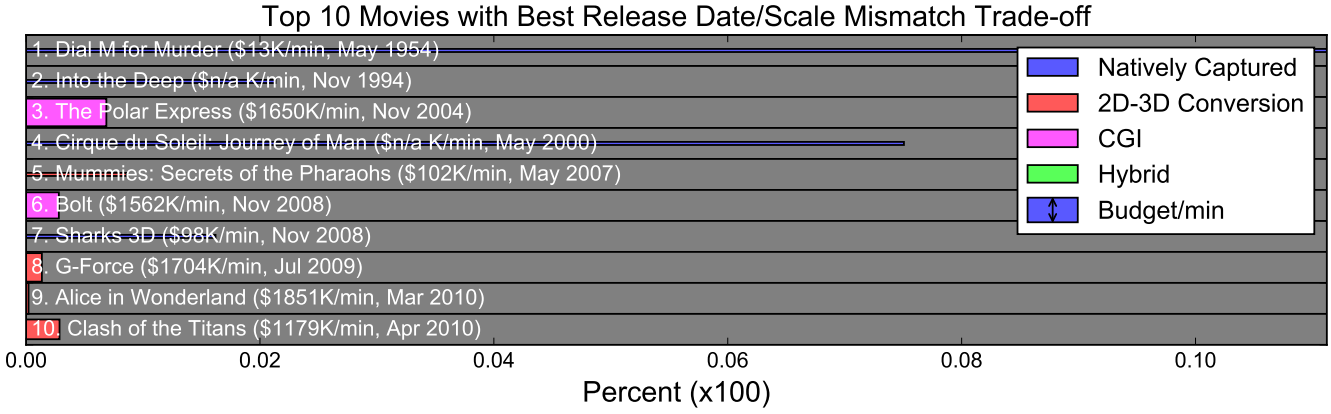


Figure 3.41: Diagram with top 10 best movies in terms of release date/scale mismatch trade-off

3.3 Rotation Mismatch

3.3.1 Budget Categories

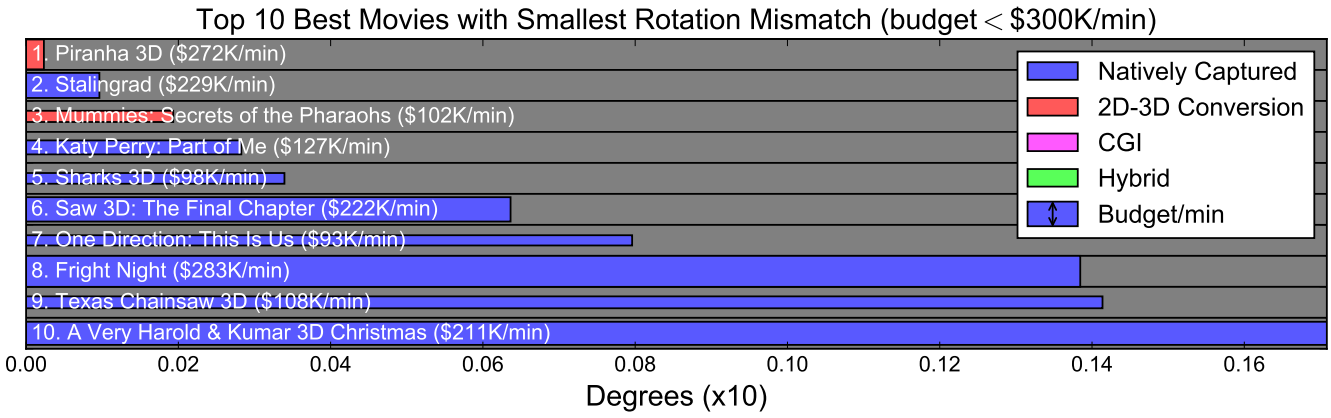


Figure 3.42: Diagram with top 10 best movies in terms of rotation mismatch with budgets less than $300K/minute

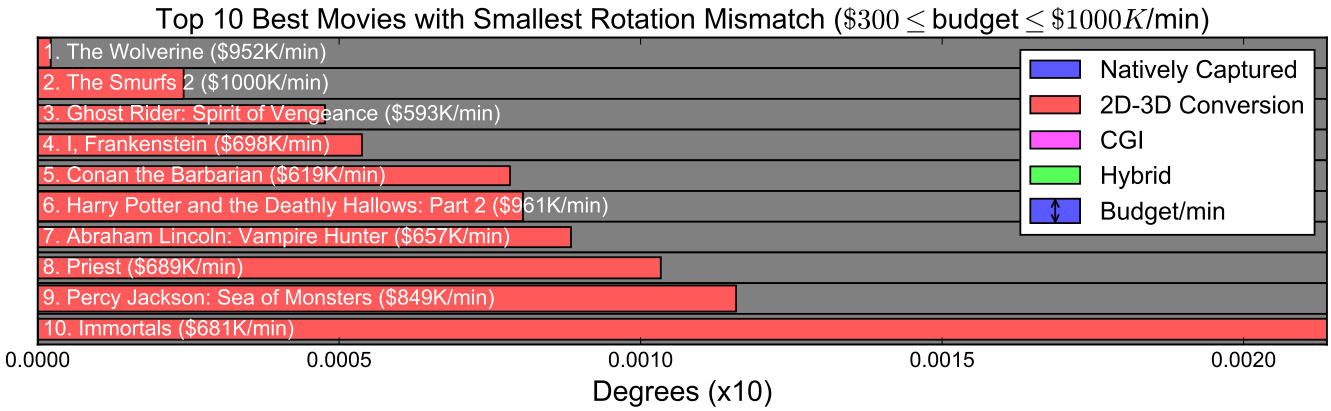


Figure 3.43: Diagram with top 10 best movies in terms of rotation mismatch with budgets less than $1000K/minute and more than $300K/minute

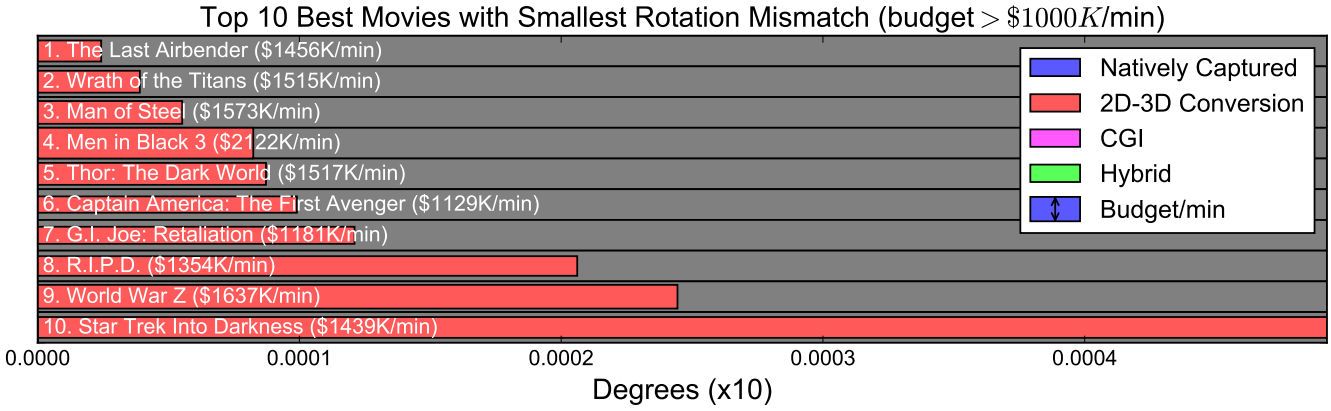


Figure 3.44: Diagram with top 10 best movies in terms of rotation mismatch with budgets more than $1000K/minute

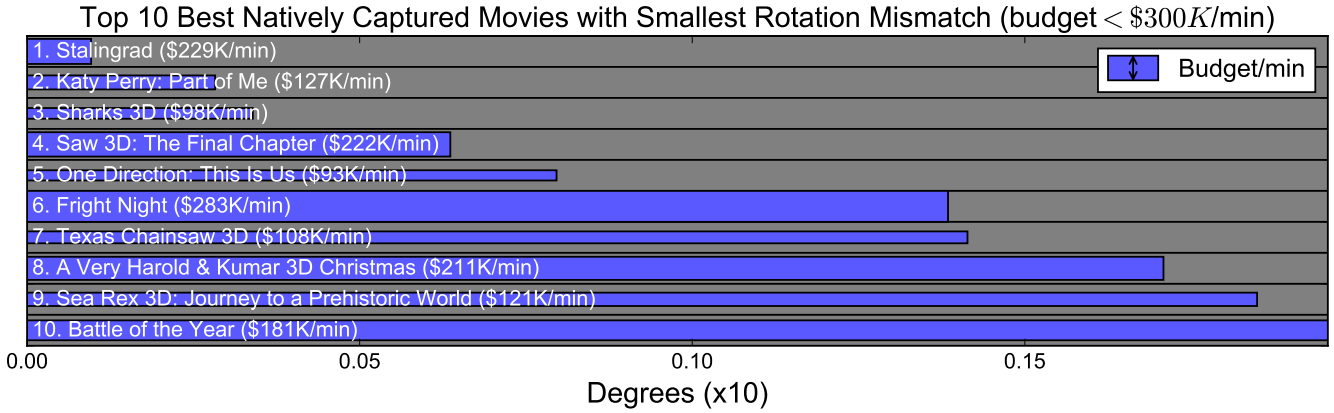


Figure 3.45: Diagram with top 10 best natively captured movies in terms of rotation mismatch with budgets less than \$300K/minute

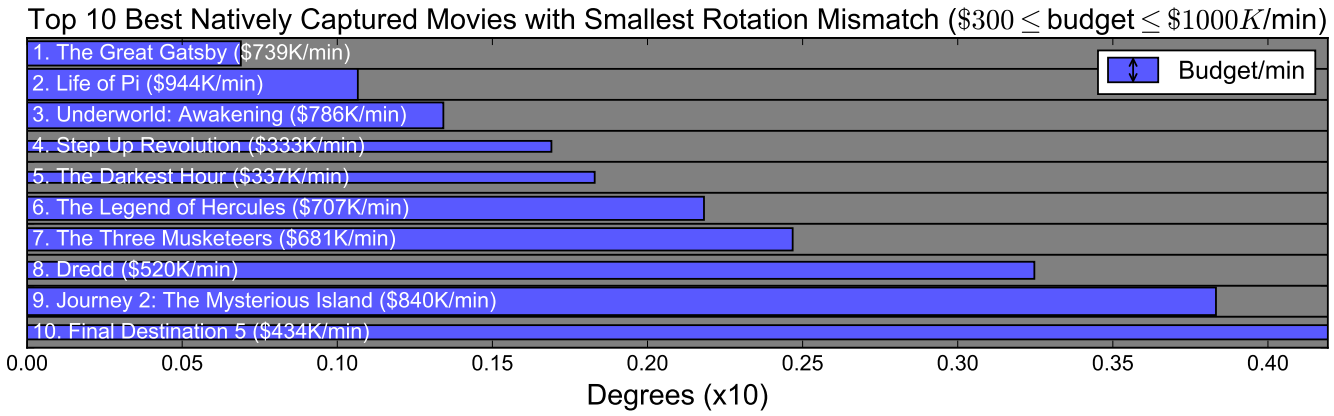


Figure 3.46: Diagram with top 10 best natively captured movies in terms of rotation mismatch with budgets less than \$1000K/minute and more than \$300K/minute

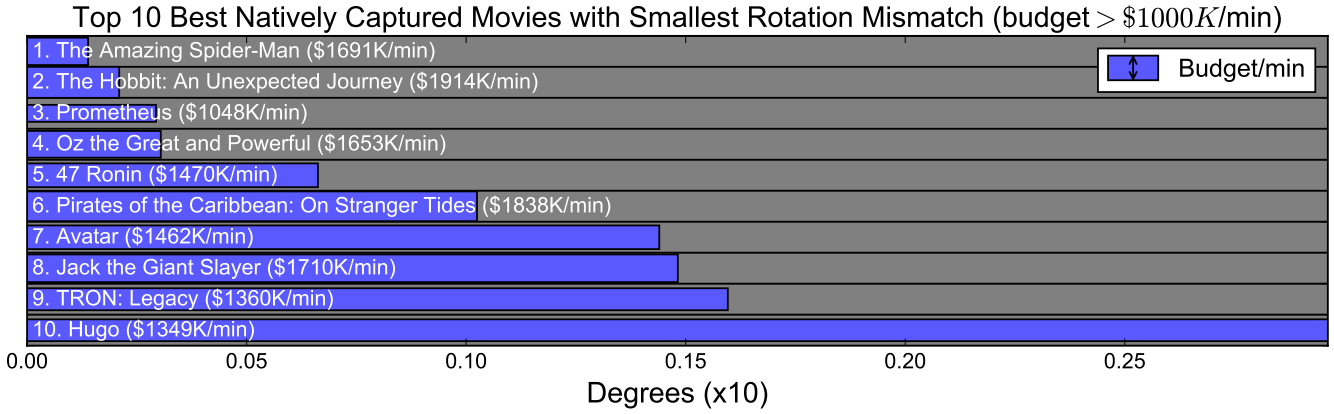


Figure 3.47: Diagram with top 10 best natively captured movies in terms of rotation mismatch with budgets more than \$1000K/minute

3.3.2 Release Date Categories

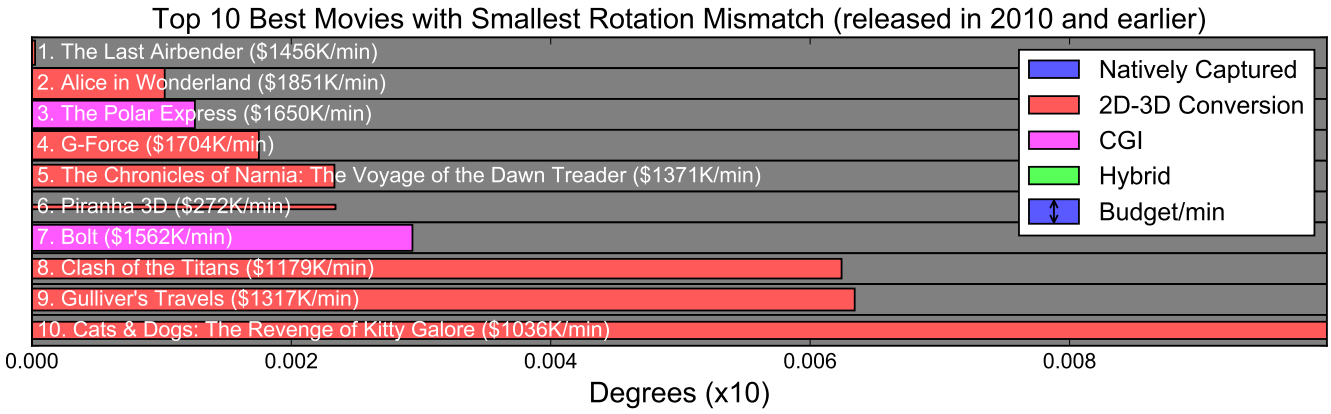


Figure 3.48: Diagram with top 10 best movies in terms of rotation mismatch released in 2010 and earlier

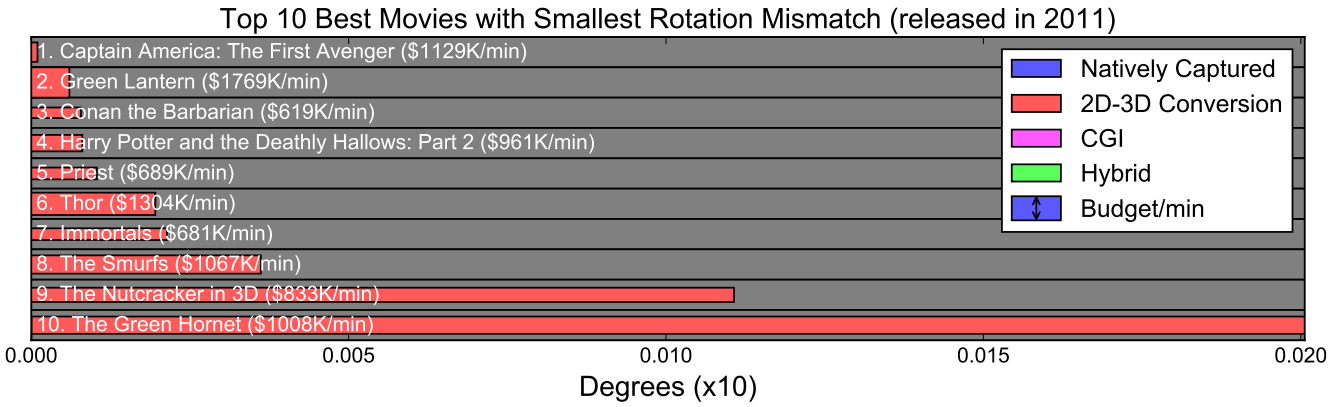


Figure 3.49: Diagram with top 10 best movies in terms of rotation mismatch released in 2011

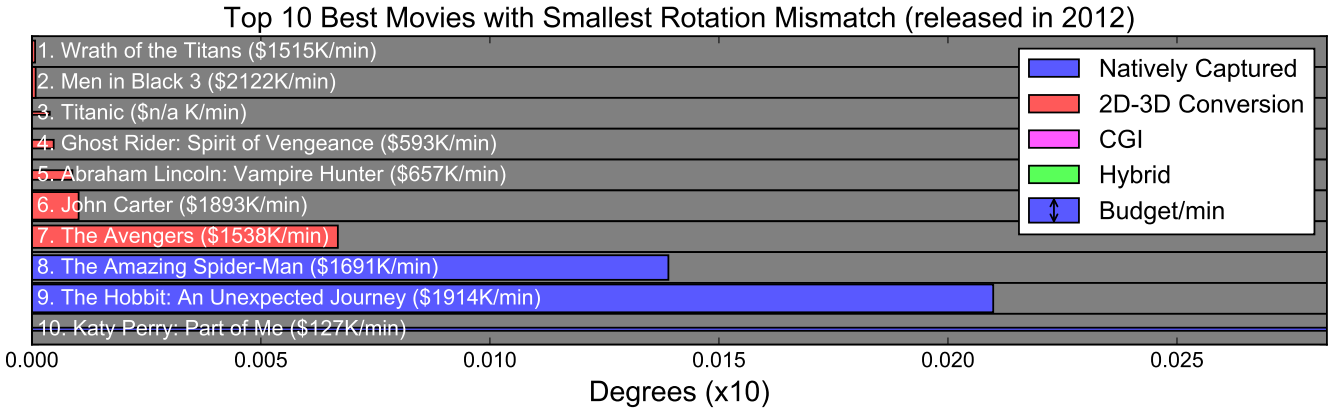


Figure 3.50: Diagram with top 10 best movies in terms of rotation mismatch released in 2012

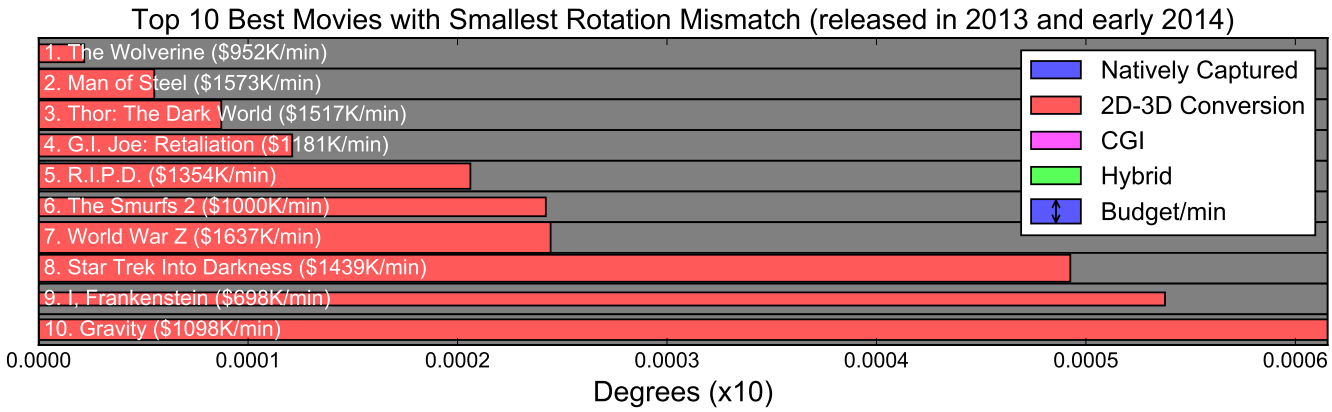


Figure 3.51: Diagram with top 10 best movies in terms of rotation mismatch released in 2013 and early 2014

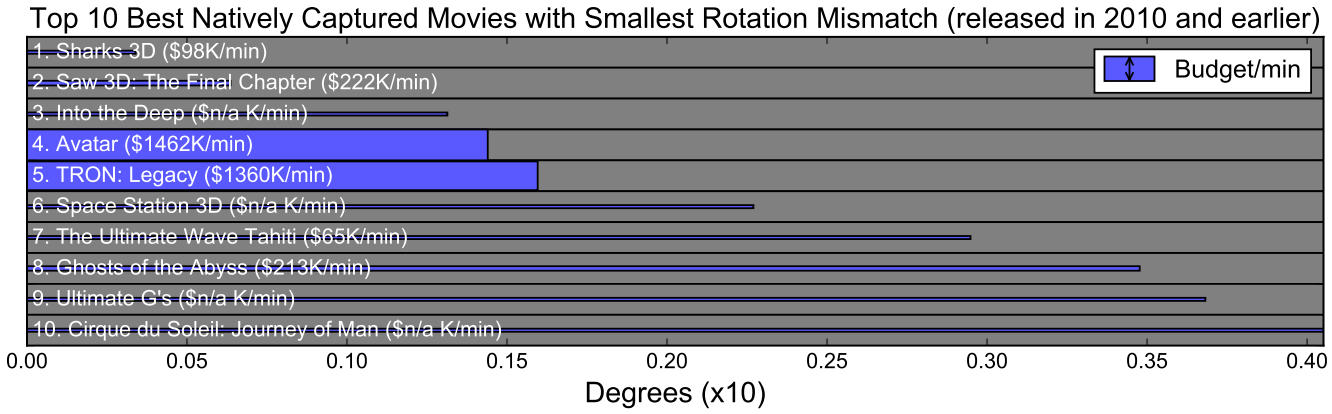


Figure 3.52: Diagram with top 10 best natively captured movies in terms of rotation mismatch released in 2010 and earlier

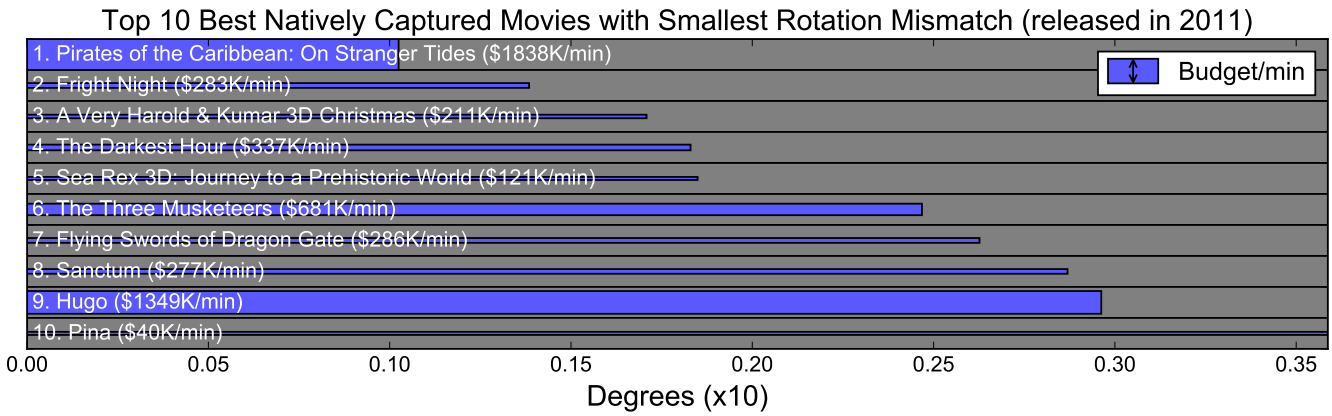


Figure 3.53: Diagram with top 10 best natively captured movies in terms of rotation mismatch released in 2011

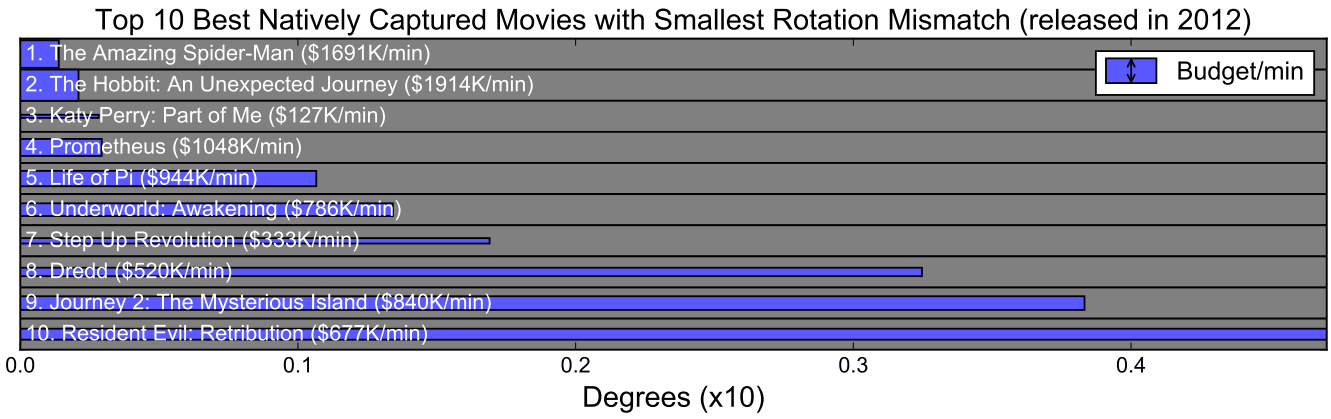


Figure 3.54: Diagram with top 10 best natively captured movies in terms of rotation mismatch released in 2012

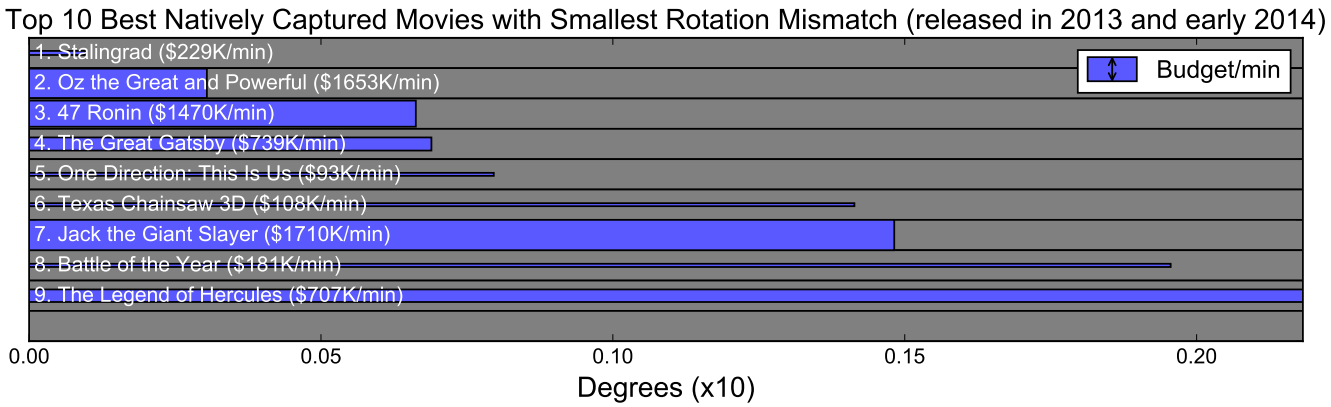


Figure 3.55: Diagram with top 10 best natively captured movies in terms of rotation mismatch released in 2013 and early 2014

3.3.3 Overall Categories

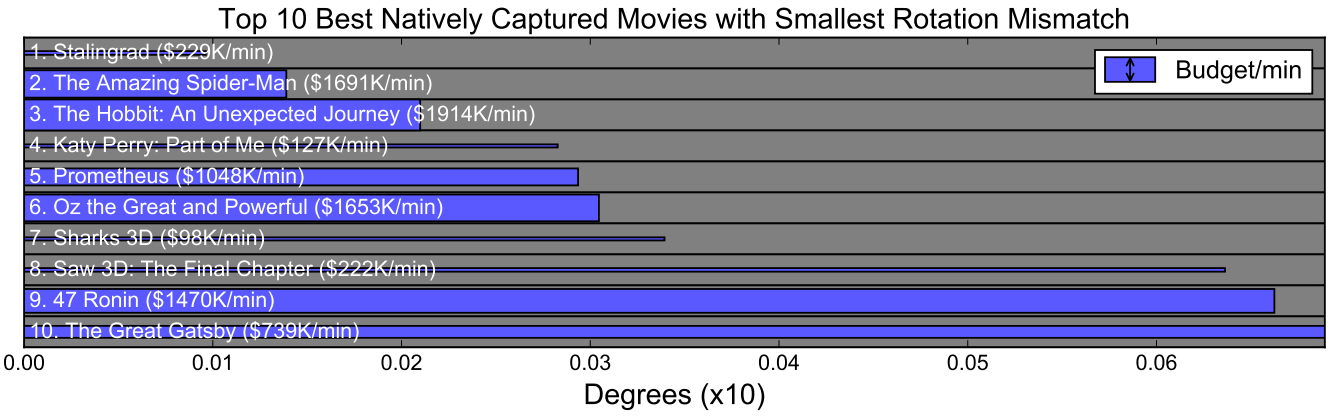


Figure 3.56: Diagram with top 10 best natively captured movies in terms of rotation mismatch

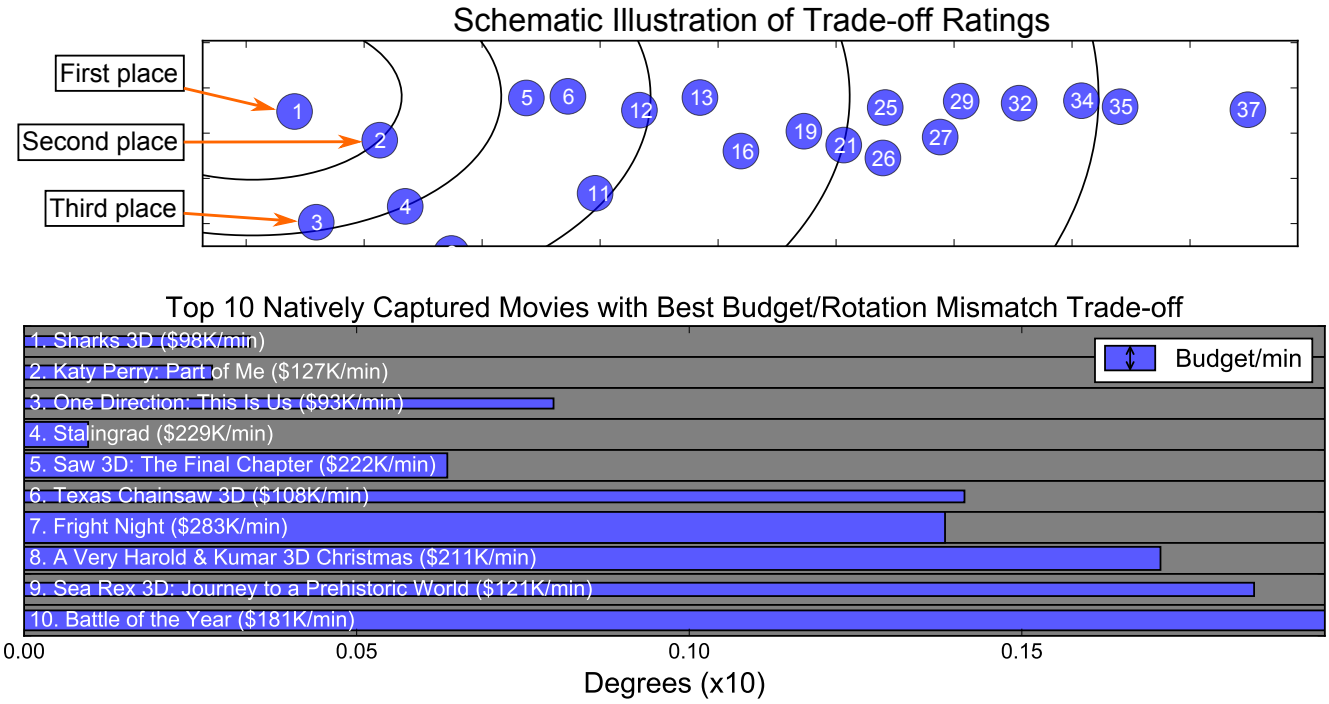


Figure 3.57: Diagram with top 10 best natively captured movies in terms of budget/rotation mismatch trade-off

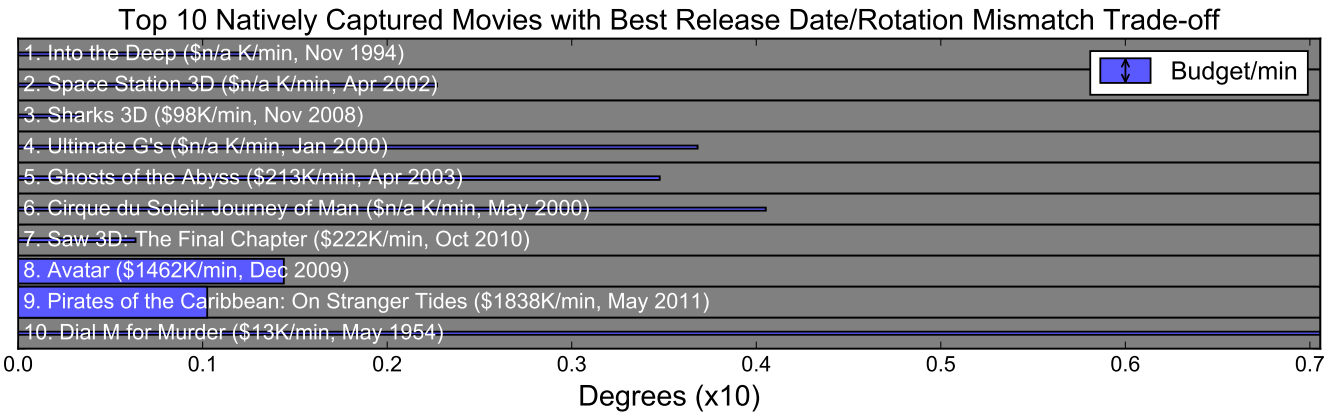


Figure 3.58: Diagram with top 10 best natively captured movies in terms of release date/rotation mismatch trade-off

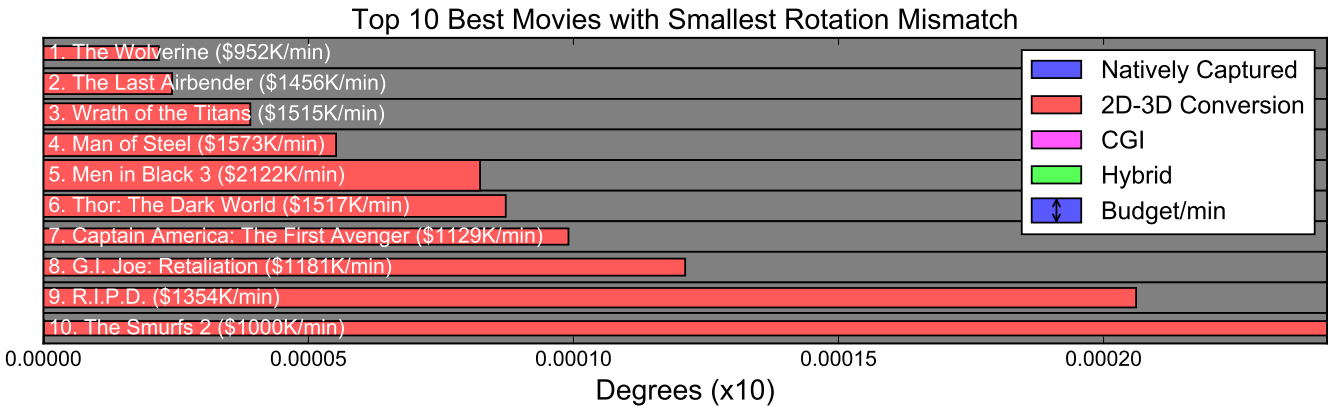


Figure 3.59: Diagram with top 10 best movies in terms of rotation mismatch

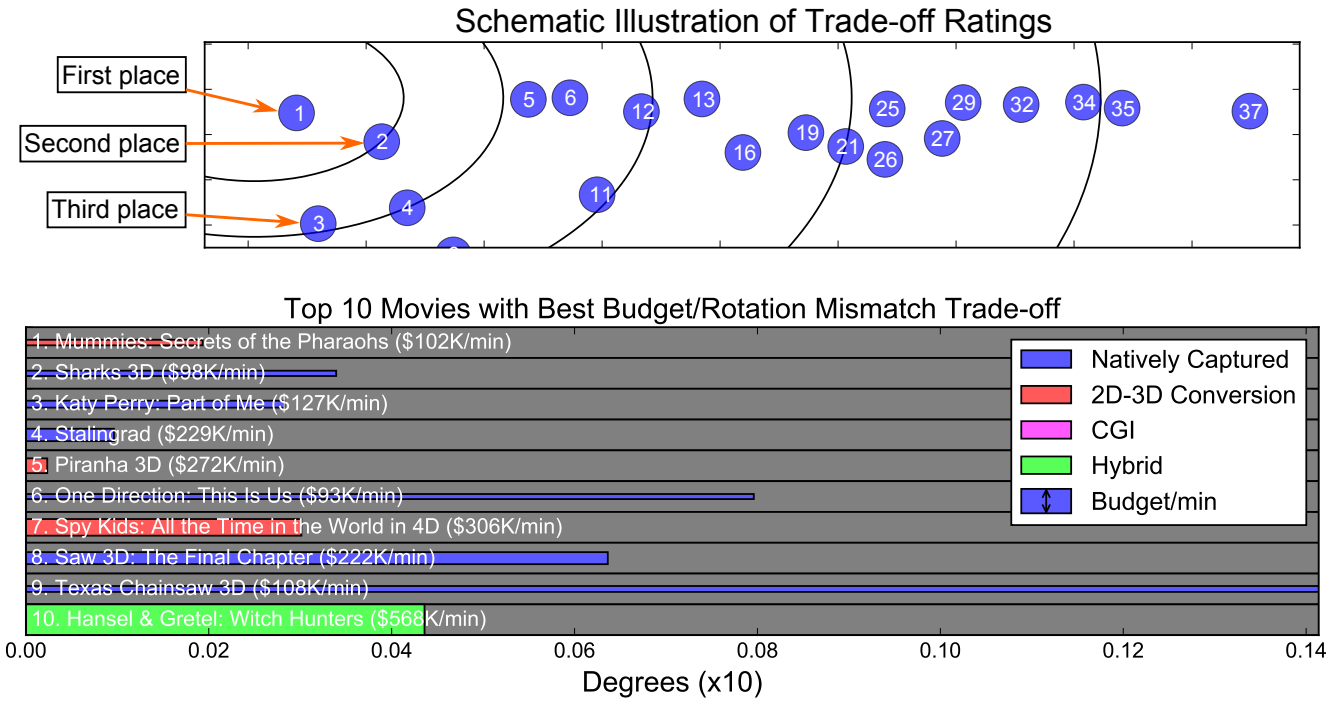


Figure 3.60: Diagram with top 10 best movies in terms of budget/rotation mismatch trade-off

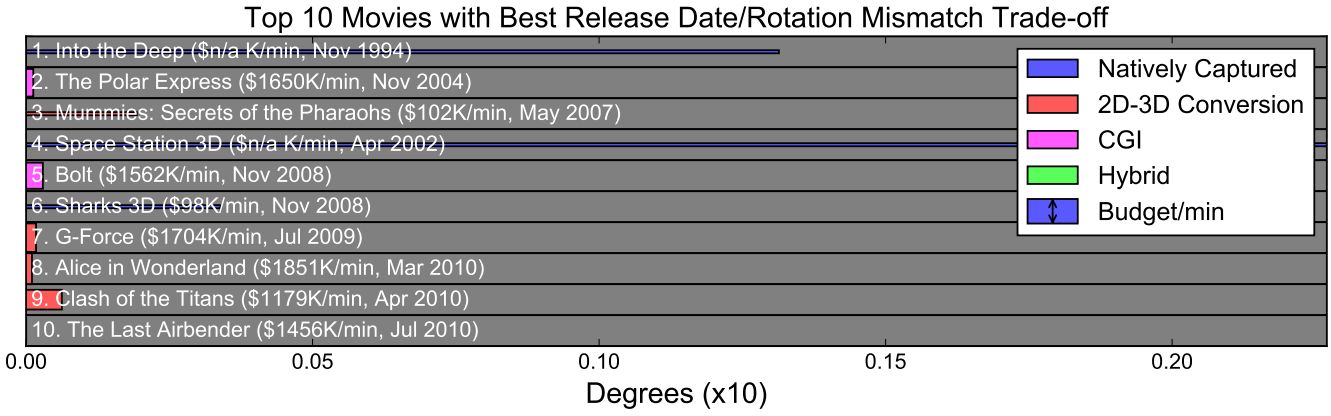


Figure 3.61: Diagram with top 10 best movies in terms of release date/rotation mismatch trade-off

3.4 Color Mismatch

3.4.1 Budget Categories

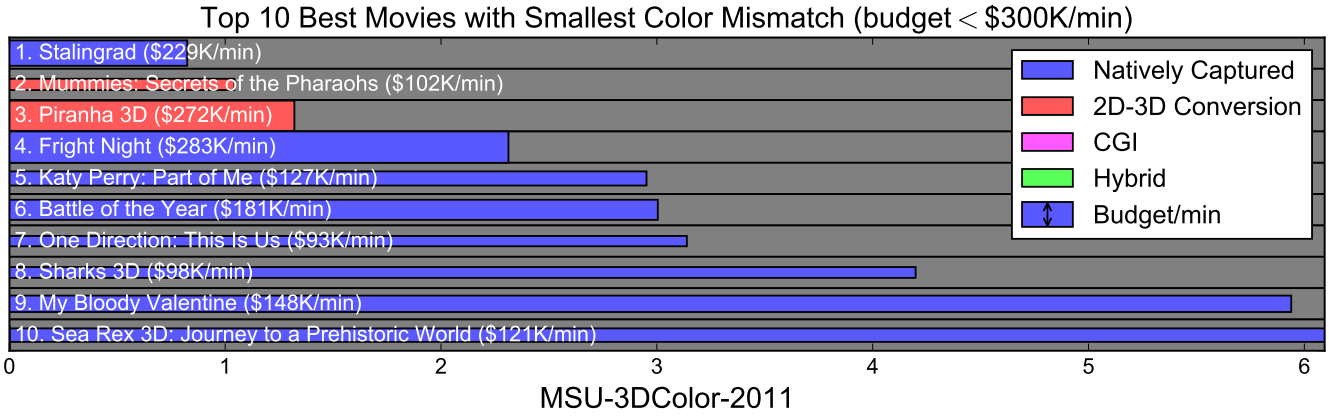


Figure 3.62: Diagram with top 10 best movies in terms of color mismatch with budgets less than $300K/minute

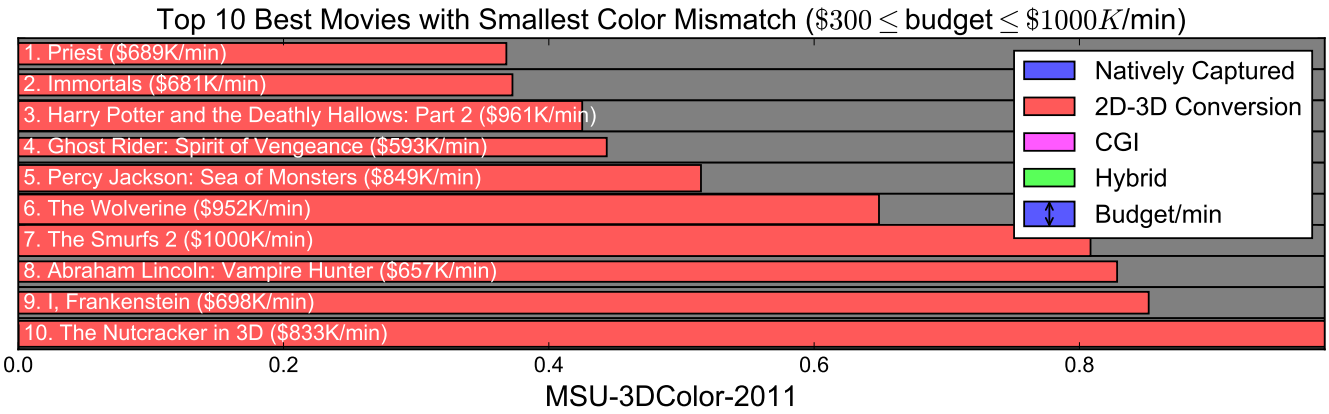


Figure 3.63: Diagram with top 10 best movies in terms of color mismatch with budgets less than $1000K/minute and more than $300K/minute

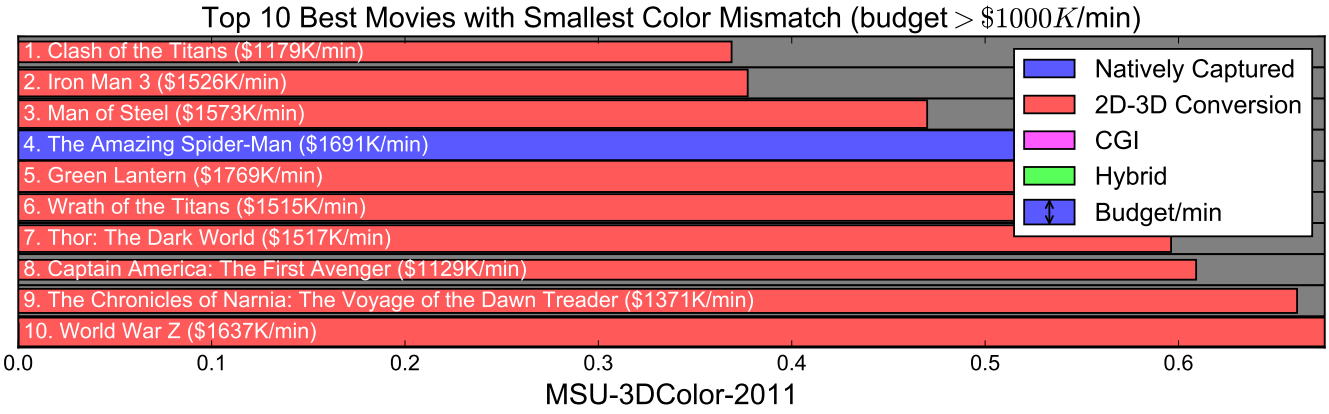


Figure 3.64: Diagram with top 10 best movies in terms of color mismatch with budgets more than $1000K/minute

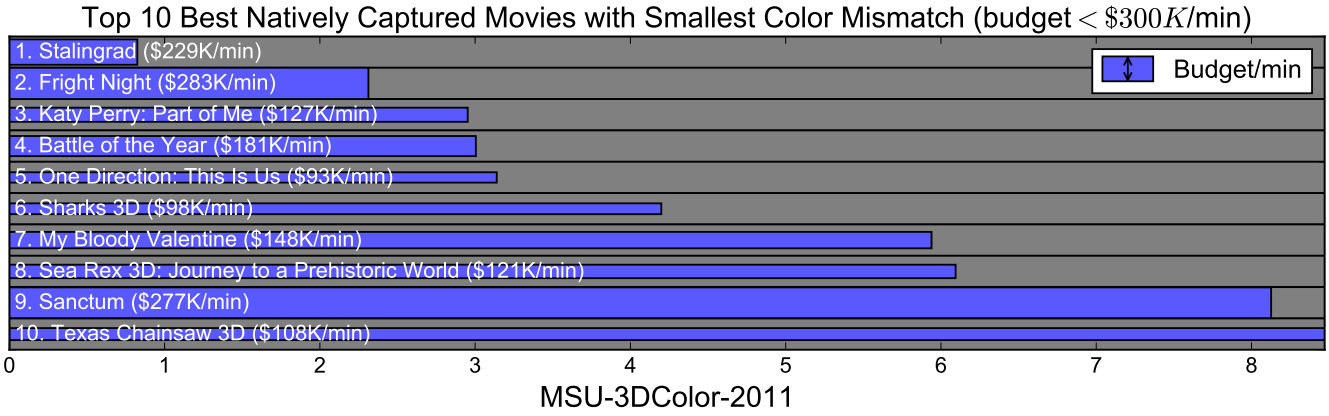


Figure 3.65: Diagram with top 10 best natively captured movies in terms of color mismatch with budgets less than \$300K/minute

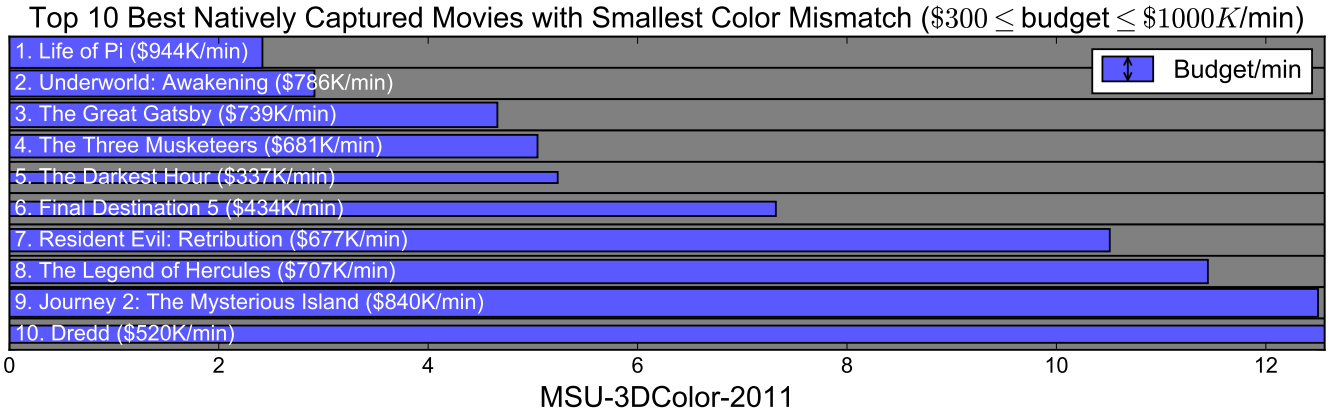


Figure 3.66: Diagram with top 10 best natively captured movies in terms of color mismatch with budgets less than \$1000K/minute and more than \$300K/minute

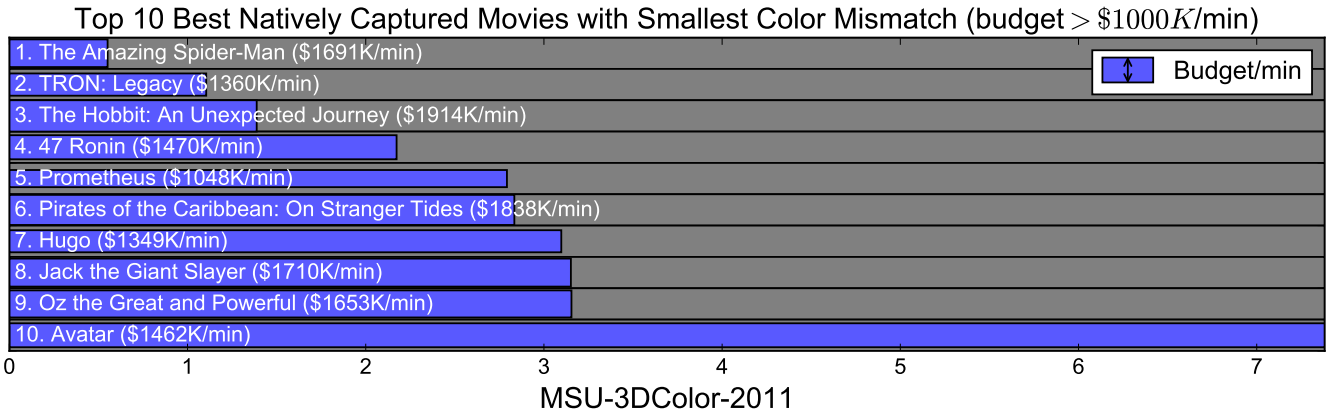


Figure 3.67: Diagram with top 10 best natively captured movies in terms of color mismatch with budgets more than \$1000K/minute

3.4.2 Release Date Categories

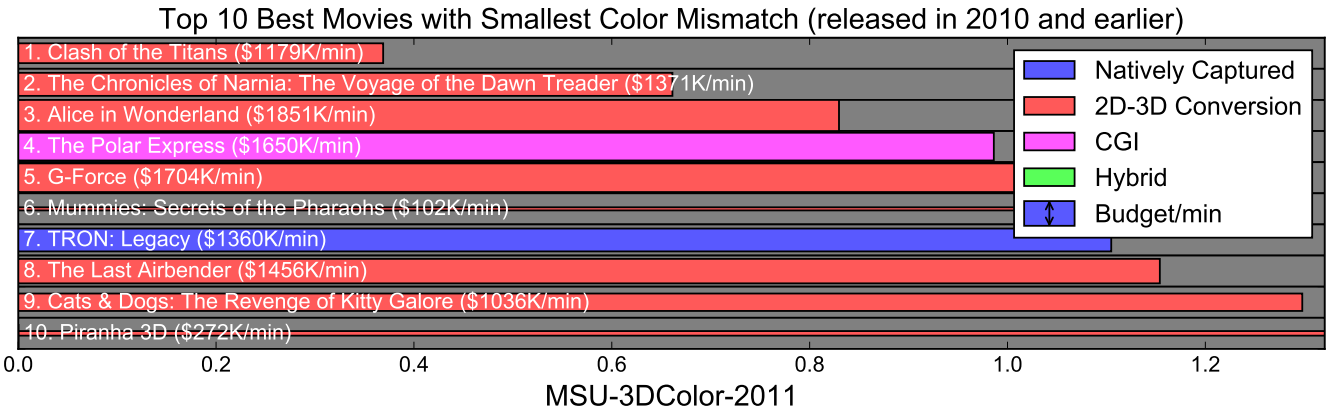


Figure 3.68: Diagram with top 10 best movies in terms of color mismatch released in 2010 and earlier

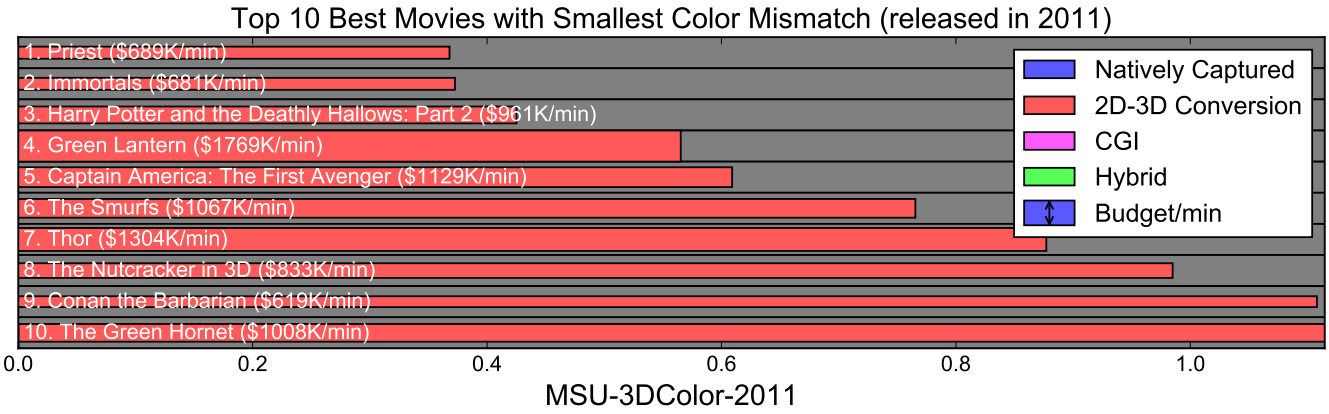


Figure 3.69: Diagram with top 10 best movies in terms of color mismatch released in 2011

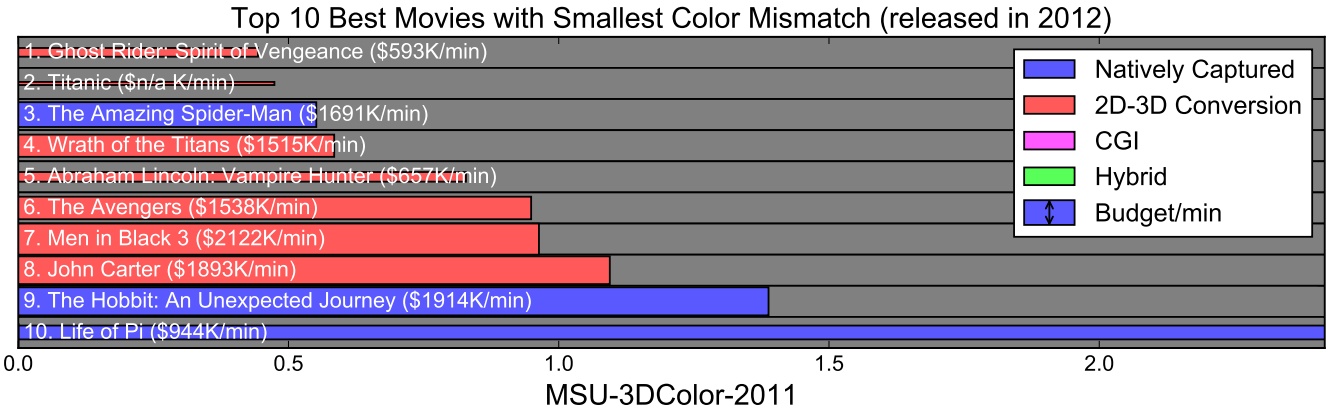


Figure 3.70: Diagram with top 10 best movies in terms of color mismatch released in 2012

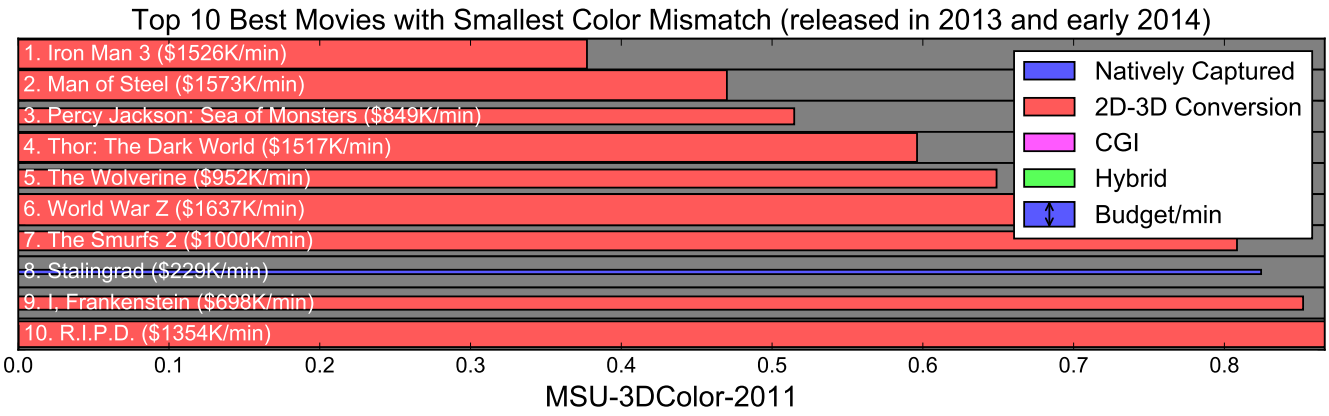


Figure 3.71: Diagram with top 10 best movies in terms of color mismatch released in 2013 and early 2014

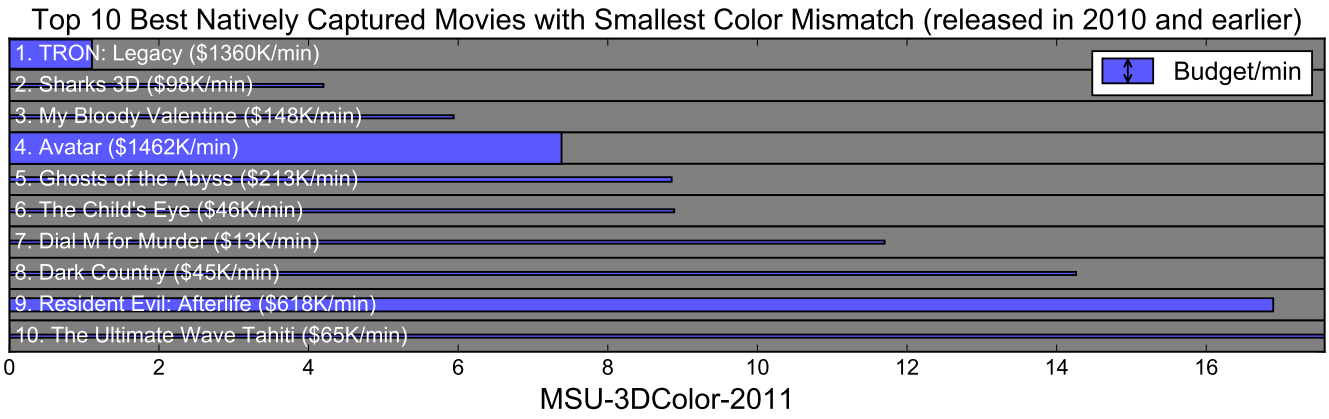


Figure 3.72: Diagram with top 10 best natively captured movies in terms of color mismatch released in 2010 and earlier

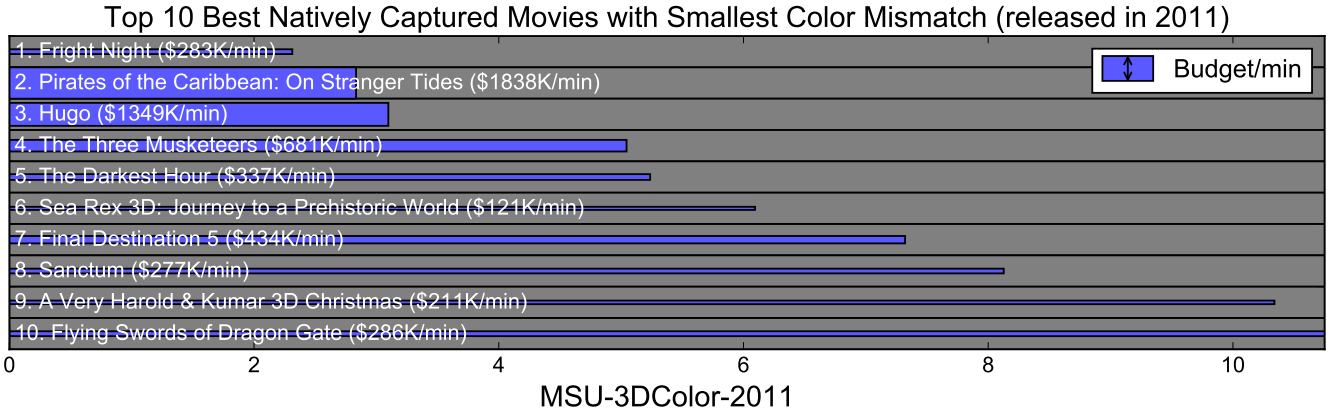


Figure 3.73: Diagram with top 10 best natively captured movies in terms of color mismatch released in 2011

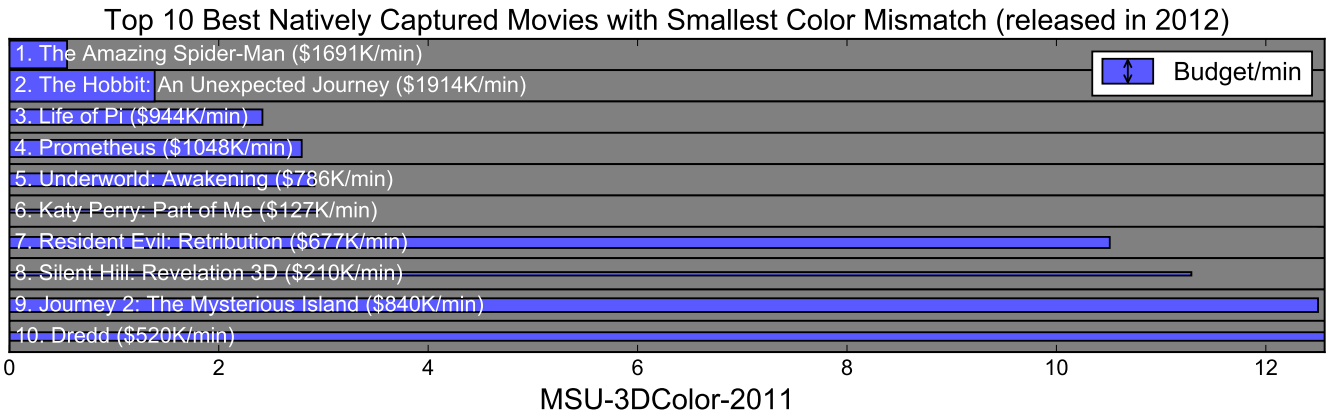


Figure 3.74: Diagram with top 10 best natively captured movies in terms of color mismatch released in 2012

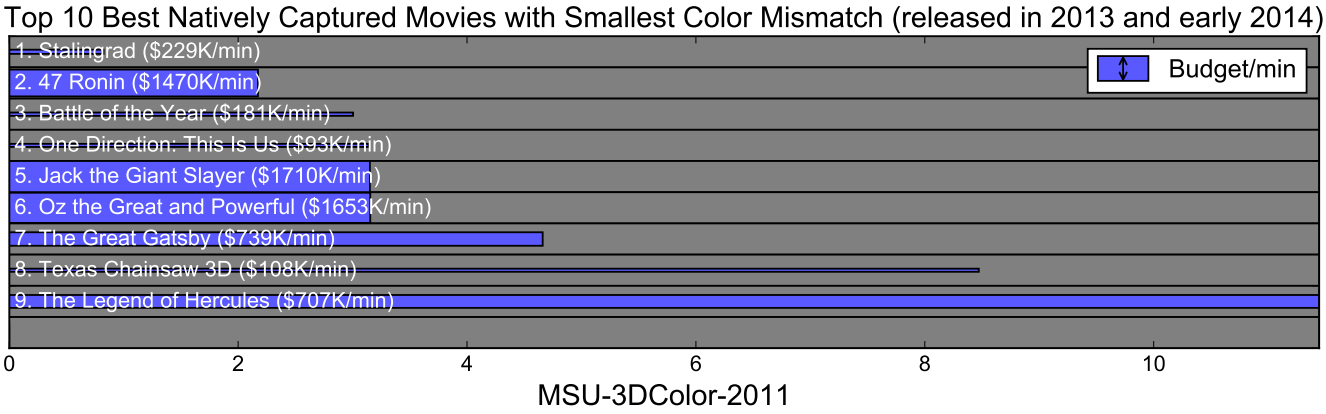


Figure 3.75: Diagram with top 10 best natively captured movies in terms of color mismatch released in 2013 and early 2014

3.4.3 Overall Categories

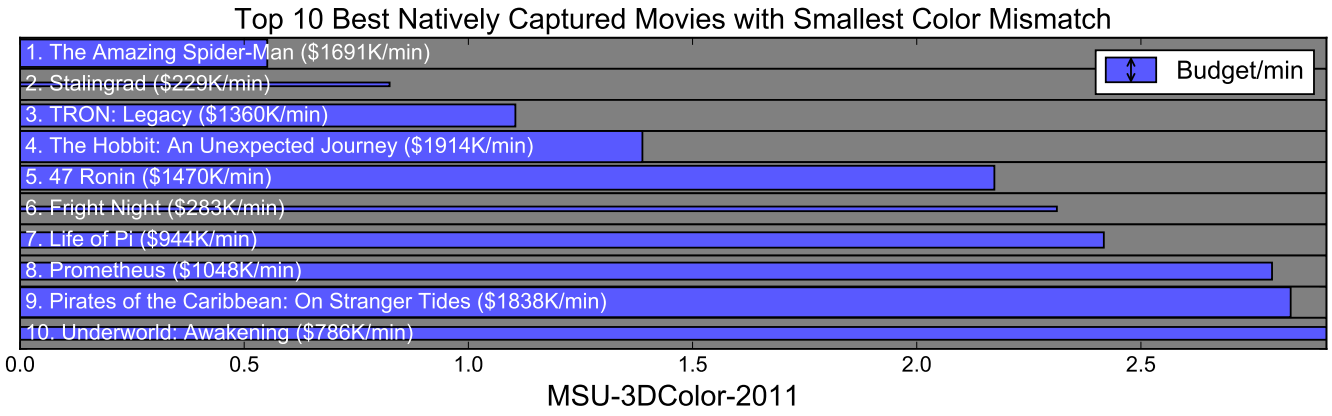


Figure 3.76: Diagram with top 10 best natively captured movies in terms of color mismatch

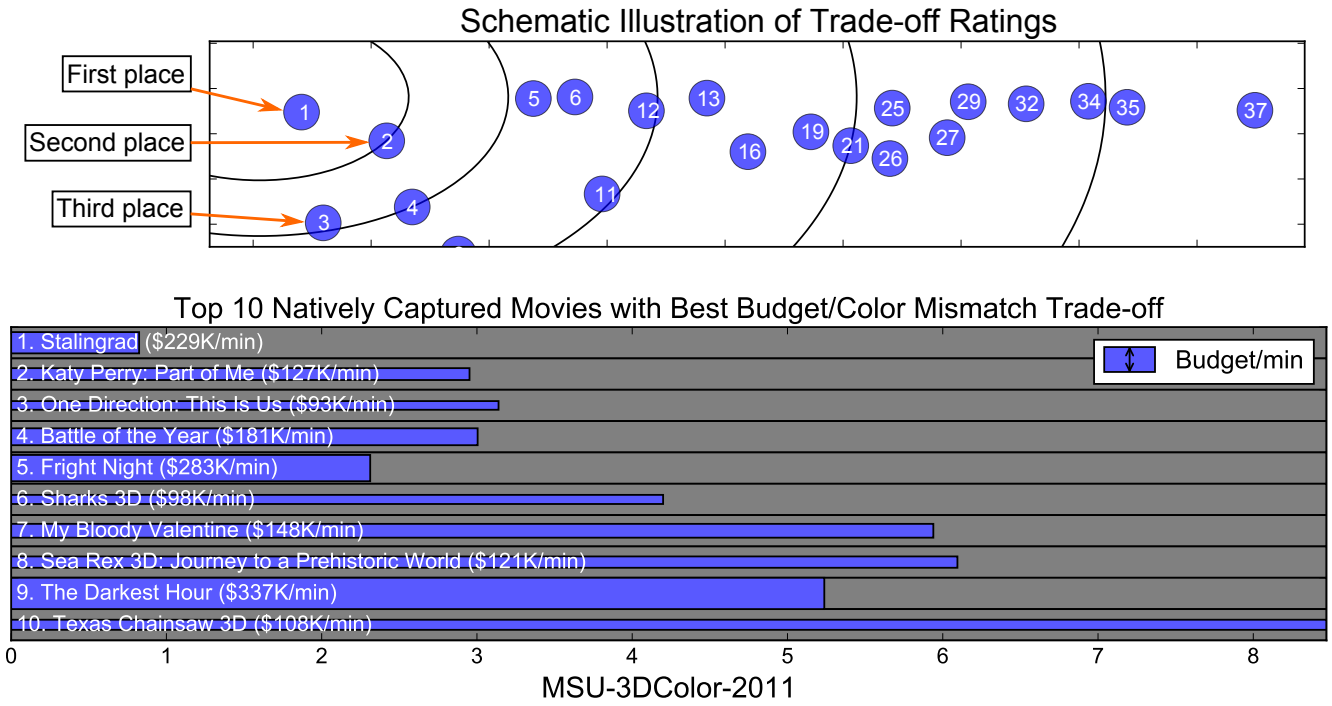


Figure 3.77: Diagram with top 10 best natively captured movies in terms of budget/color mismatch trade-off

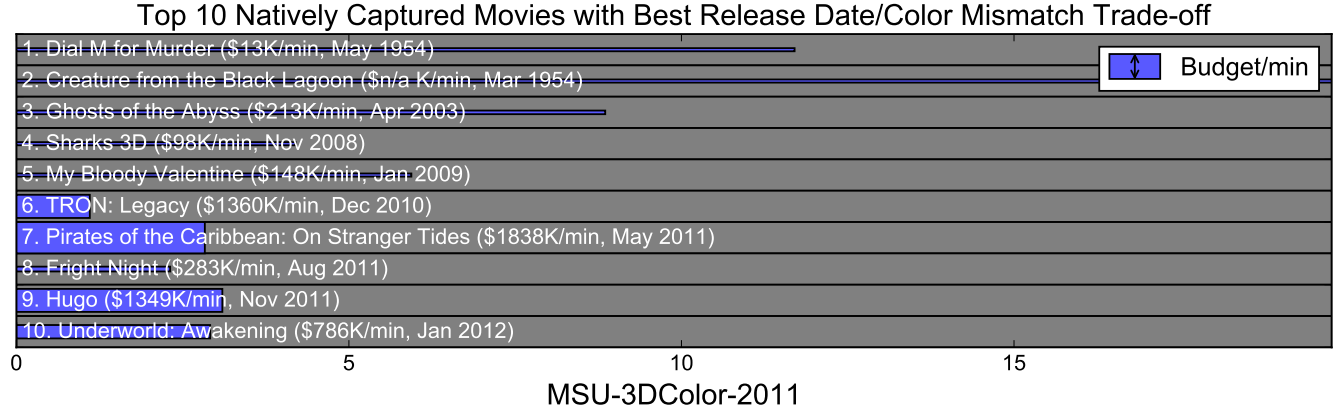


Figure 3.78: Diagram with top 10 best natively captured movies in terms of release date/color mismatch trade-off

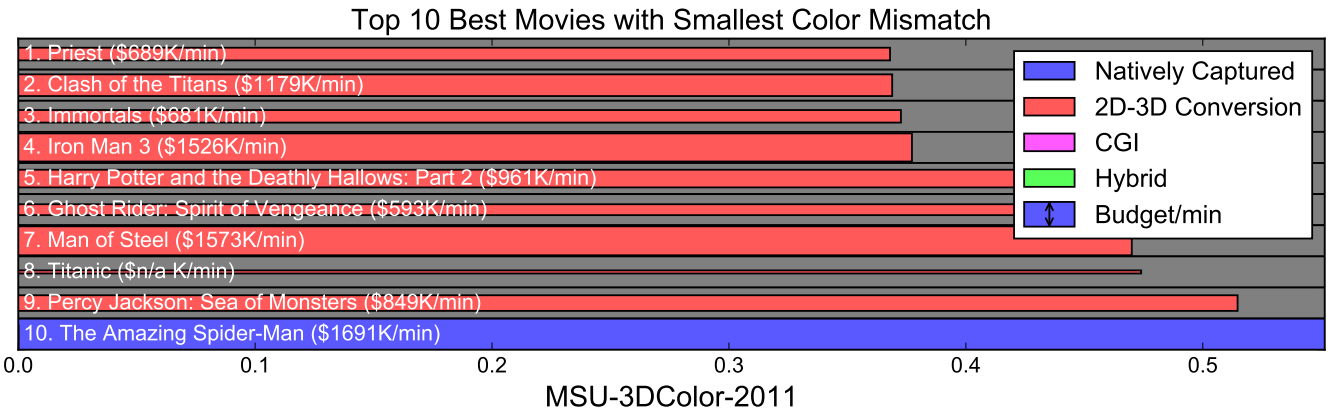


Figure 3.79: Diagram with top 10 best movies in terms of color mismatch

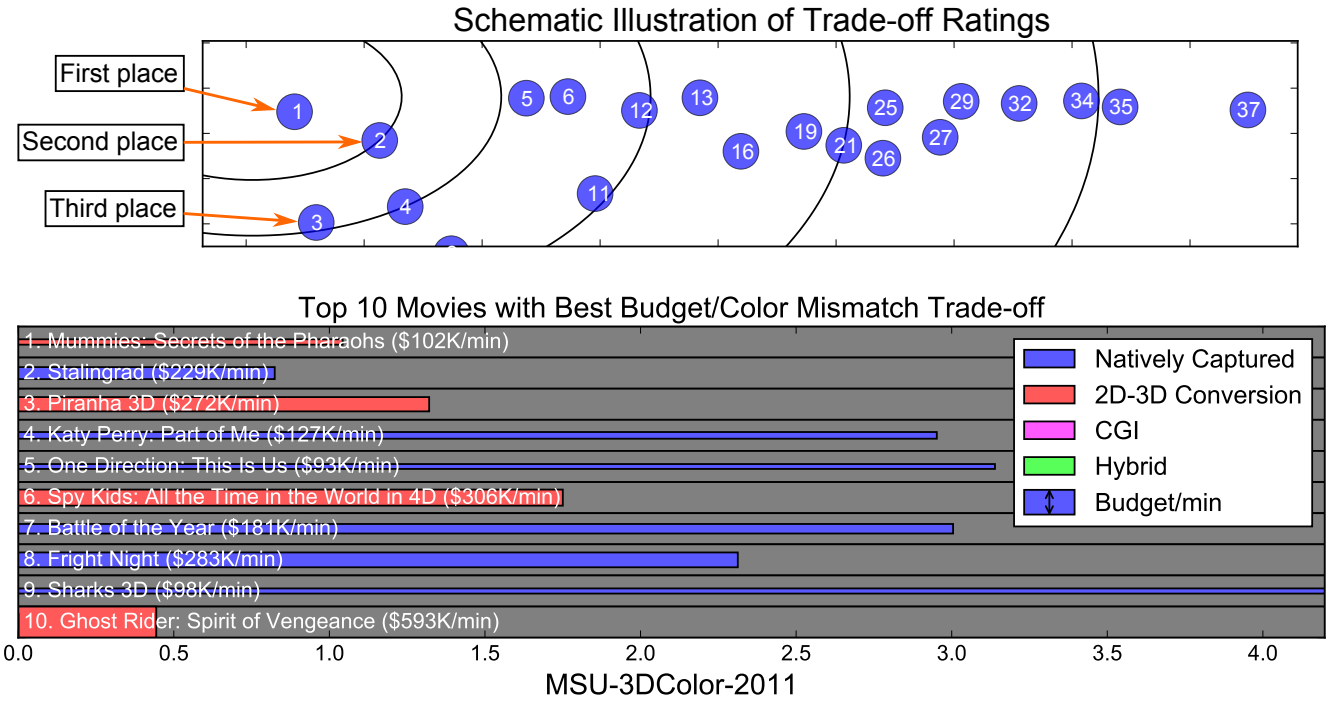


Figure 3.80: Diagram with top 10 best movies in terms of budget/color mismatch trade-off

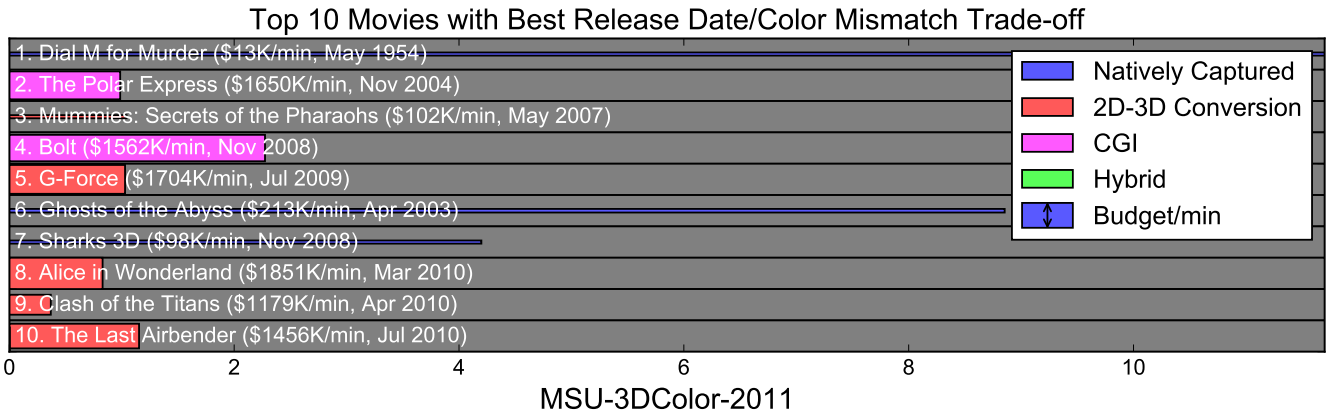


Figure 3.81: Diagram with top 10 best movies in terms of release date/color mismatch trade-off

3.5 Sharpness Mismatch

3.5.1 Budget Categories

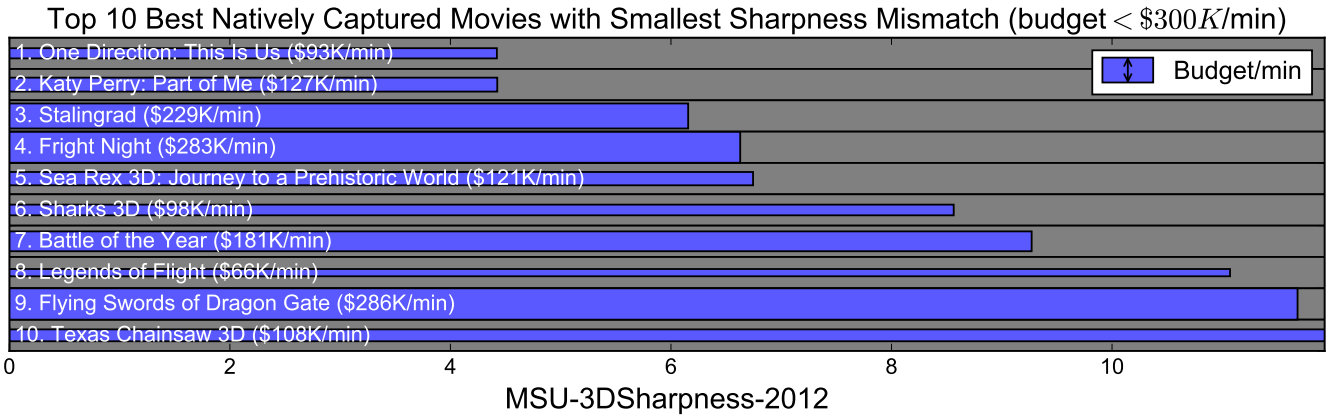


Figure 3.82: Diagram with top 10 best natively captured movies in terms of sharpness mismatch with budgets less than \$300K/minute

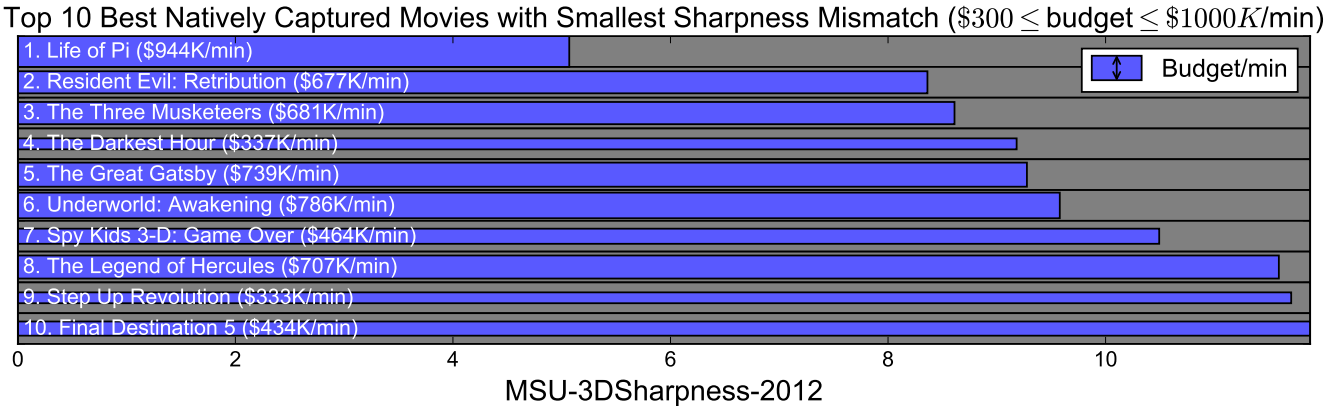


Figure 3.83: Diagram with top 10 best natively captured movies in terms of sharpness mismatch with budgets less than \$1000K/minute and more than \$300K/minute

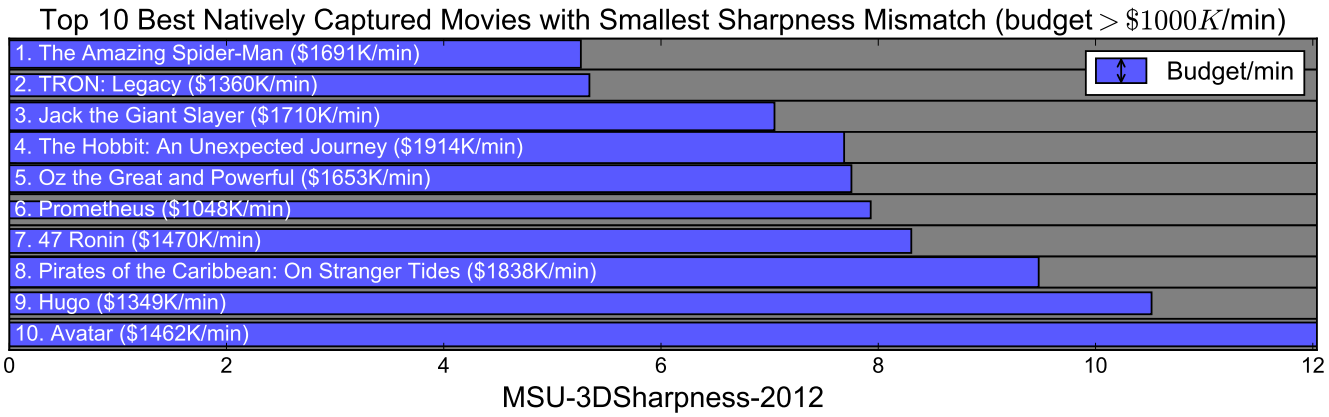


Figure 3.84: Diagram with top 10 best natively captured movies in terms of sharpness mismatch with budgets more than \$1000K/minute

3.5.2 Release Date Categories

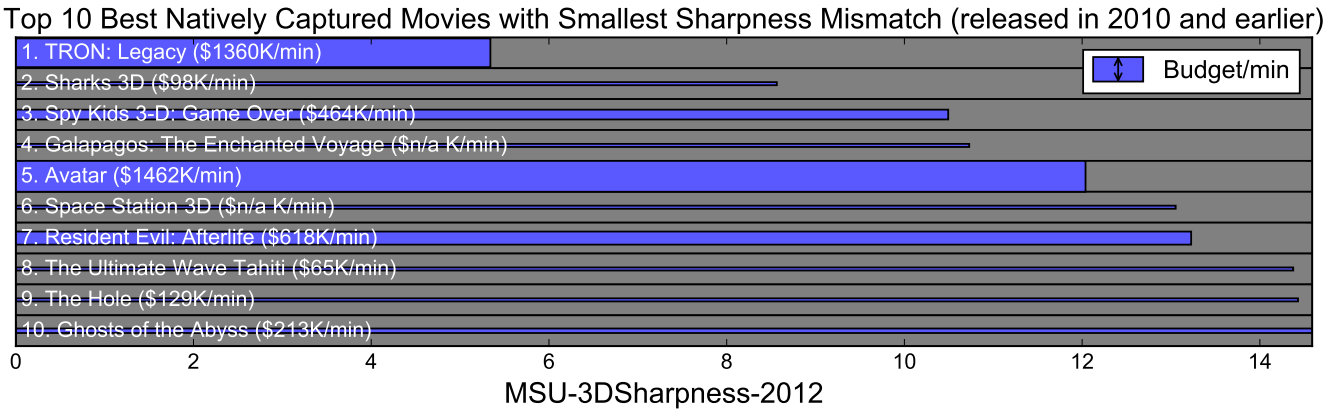


Figure 3.85: Diagram with top 10 best natively captured movies in terms of sharpness mismatch released in 2010 and earlier

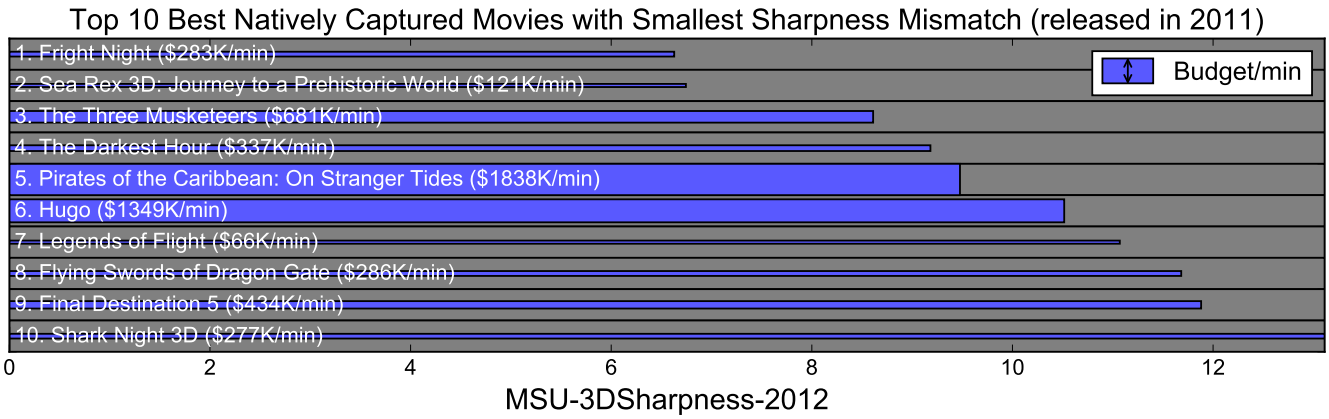


Figure 3.86: Diagram with top 10 best natively captured movies in terms of sharpness mismatch released in 2011

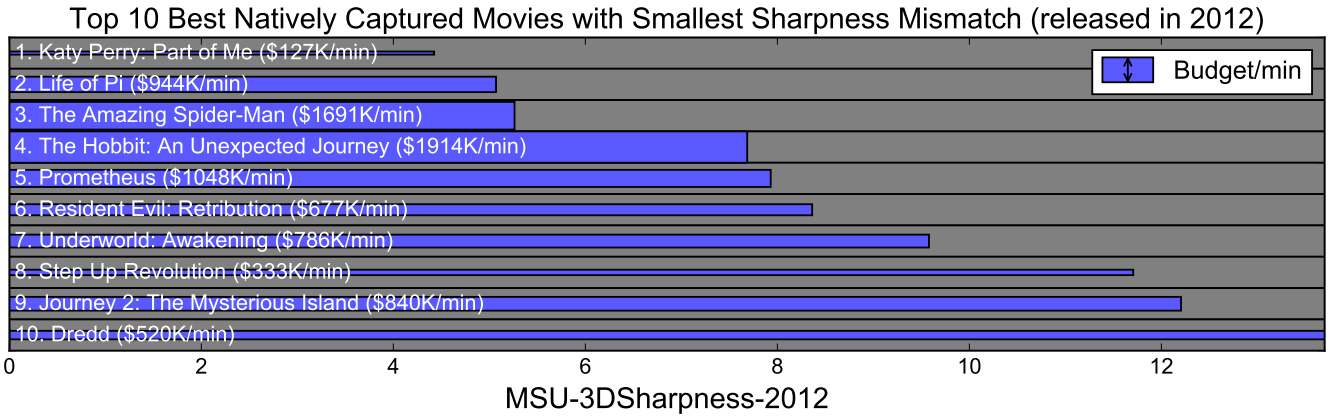


Figure 3.87: Diagram with top 10 best natively captured movies in terms of sharpness mismatch released in 2012

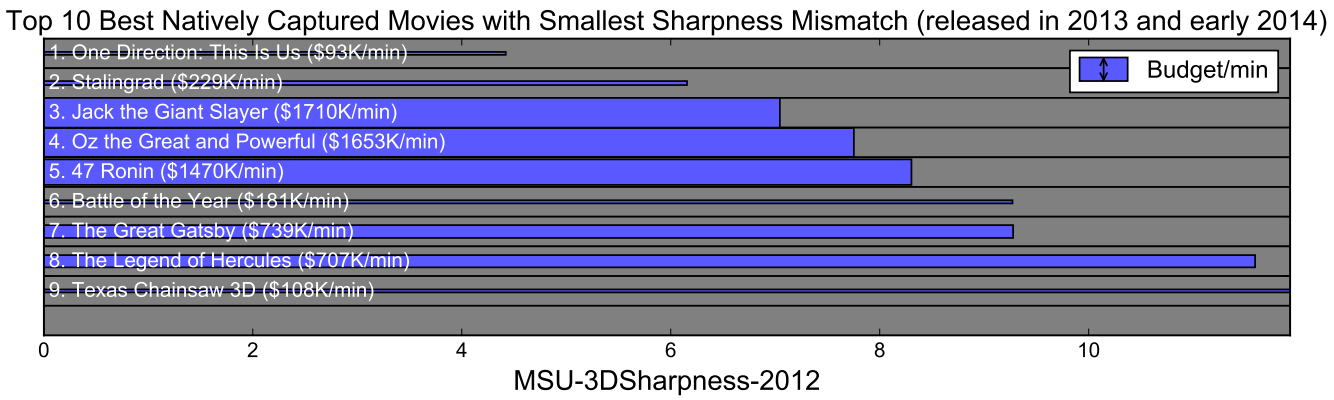


Figure 3.88: Diagram with top 10 best natively captured movies in terms of sharpness mismatch released in 2013 and early 2014

3.5.3 Overall Categories

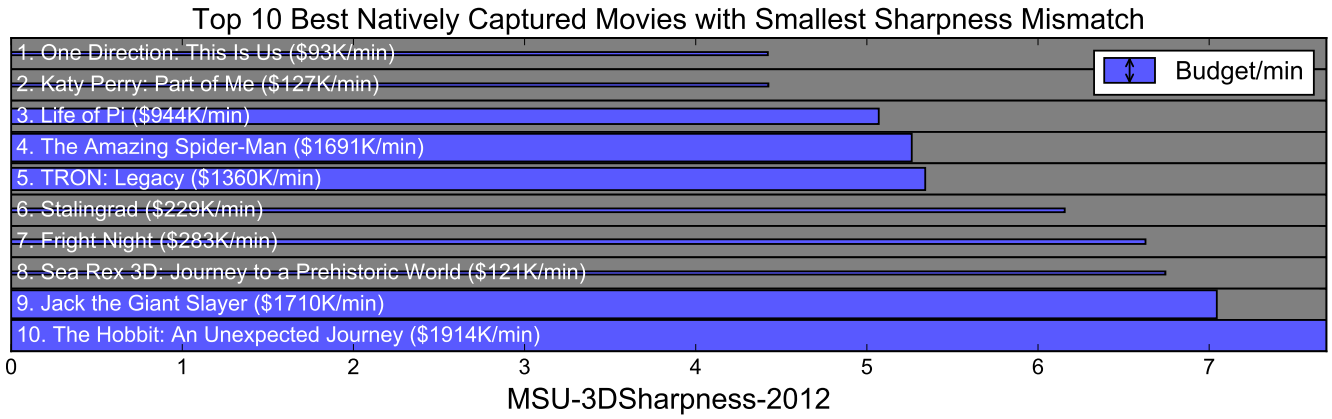
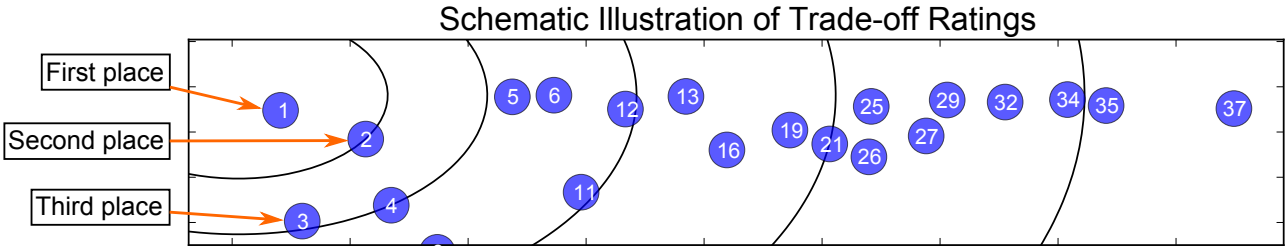


Figure 3.89: Diagram with top 10 best natively captured movies in terms of sharpness mismatch



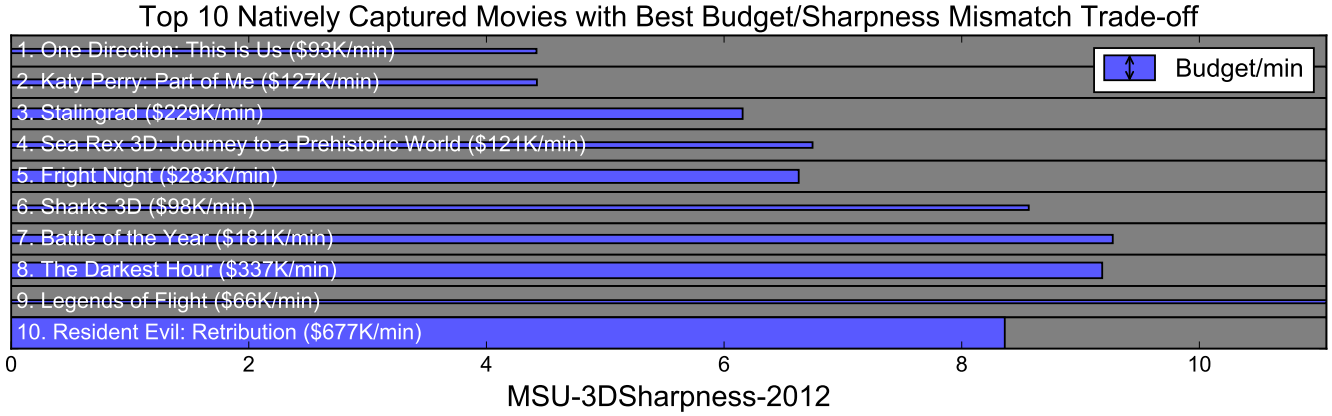


Figure 3.90: Diagram with top 10 best natively captured movies in terms of budget/sharpness mismatch trade-off

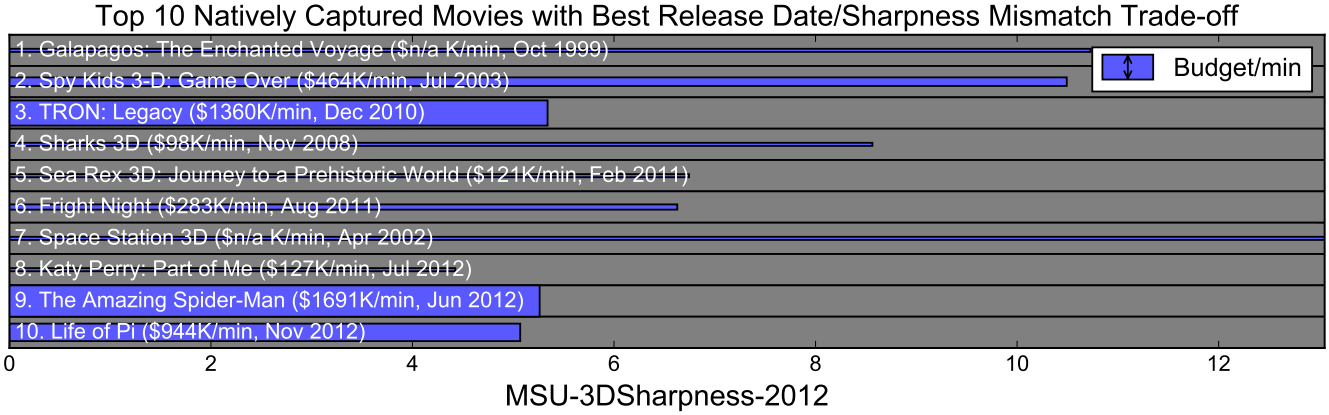


Figure 3.91: Diagram with top 10 best natively captured movies in terms of release date/sharpness mismatch trade-off

3.6 Stereo Window Violation

3.6.1 Budget Categories

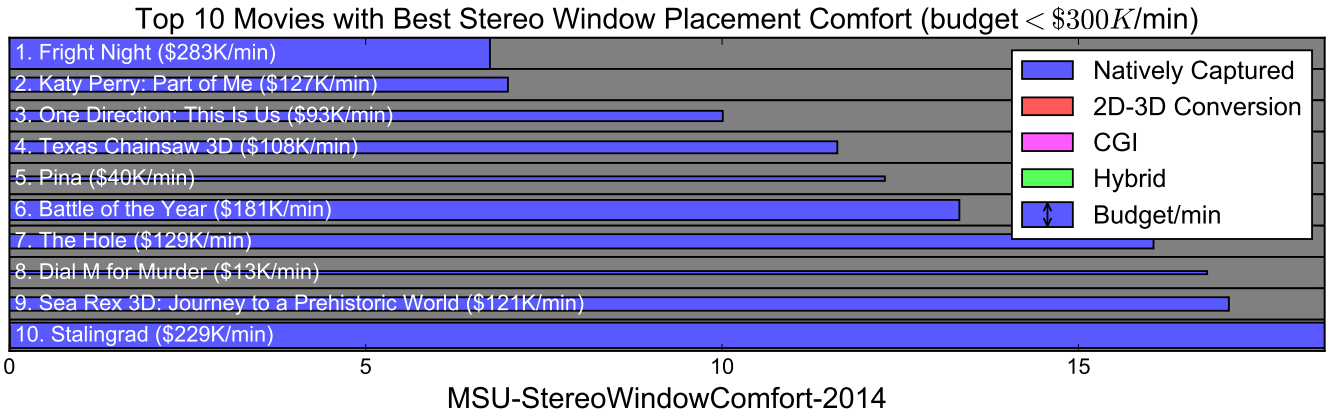


Figure 3.92: Diagram with top 10 best movies in terms of stereo window placement comfort with budgets less than \$300K/minute

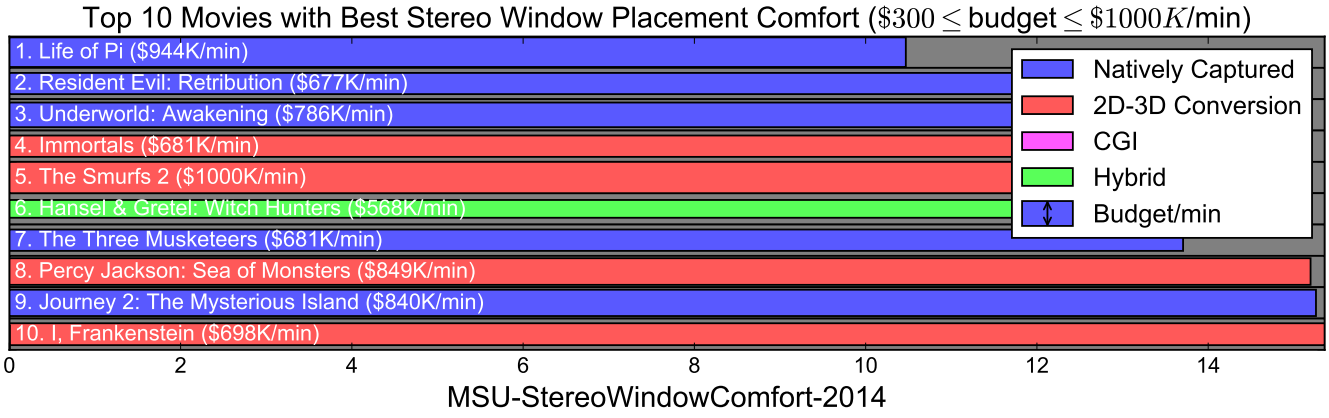


Figure 3.93: Diagram with top 10 best movies in terms of stereo window placement comfort with budgets less than \$1000K/minute and more than \$300K/minute

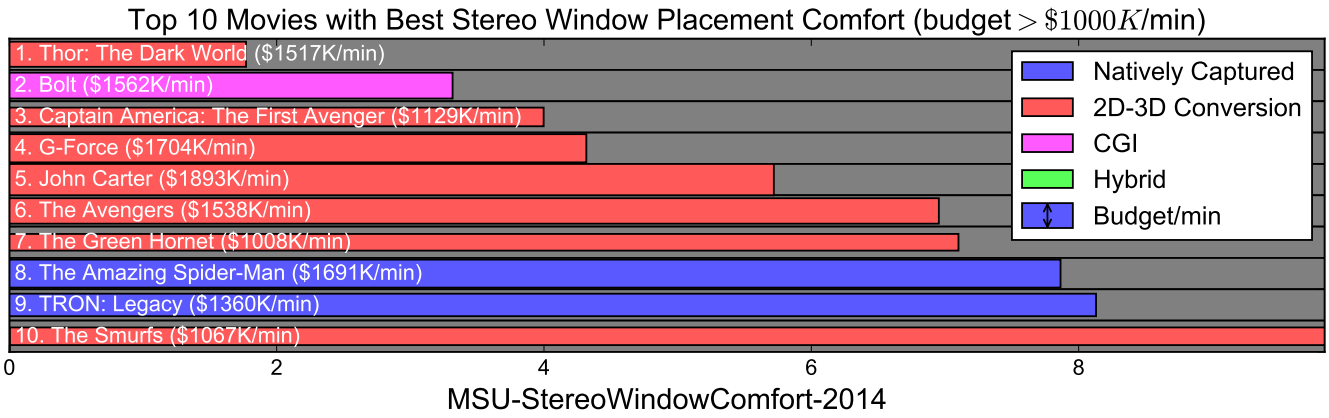


Figure 3.94: Diagram with top 10 best movies in terms of stereo window placement comfort with budgets more than \$1000K/minute

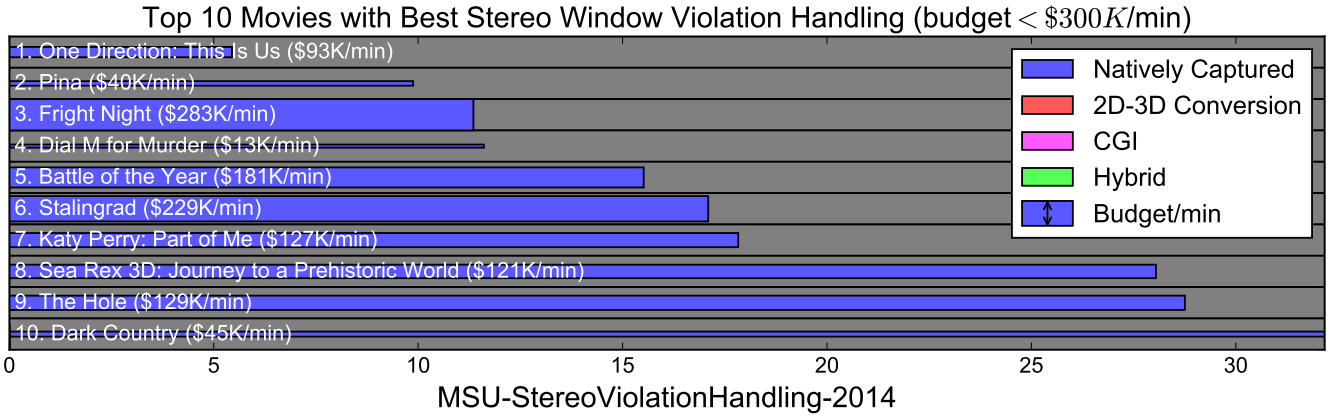


Figure 3.95: Diagram with top 10 best movies in terms of stereo window violation handling with budgets less than \$300K/minute

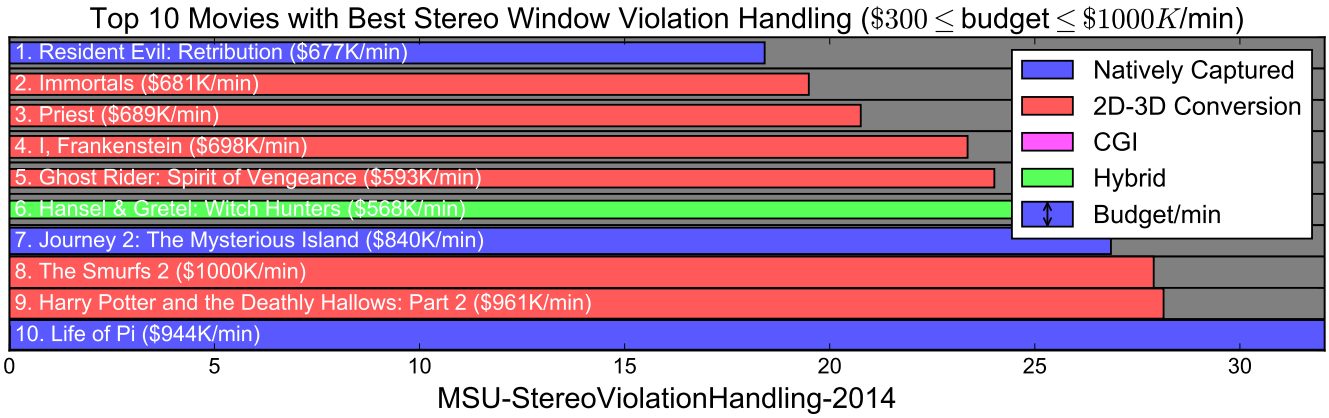


Figure 3.96: Diagram with top 10 best movies in terms of stereo window violation handling with budgets less than \$1000K/minute and more than \$300K/minute

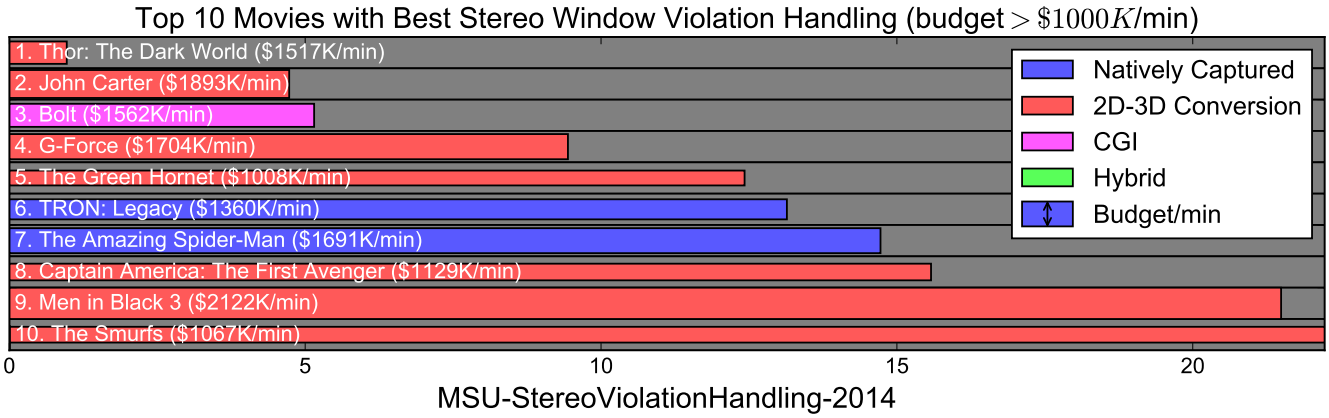


Figure 3.97: Diagram with top 10 best movies in terms of stereo window violation handling with budgets more than \$1000K/minute

3.6.2 Release Date Categories

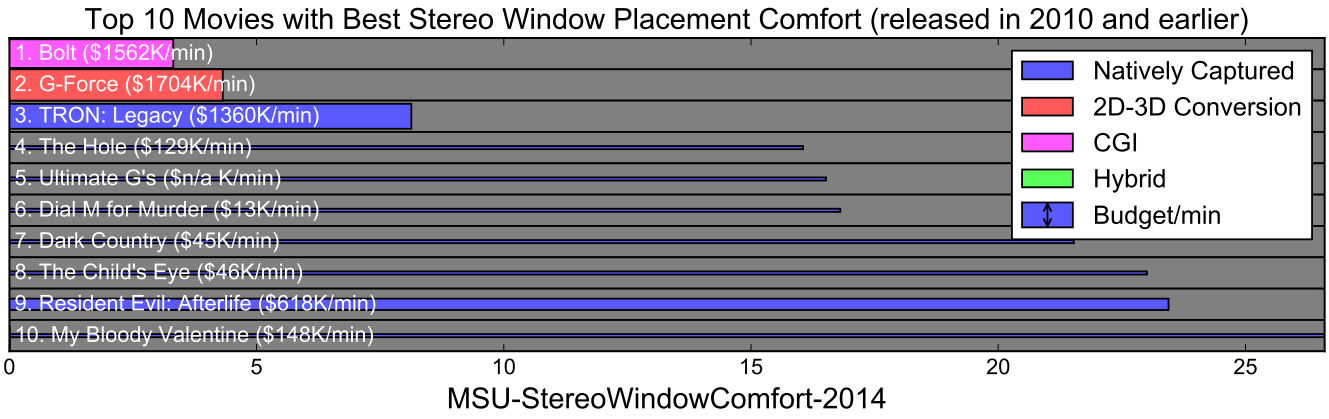


Figure 3.98: Diagram with top 10 best movies in terms of stereo window placement comfort released in 2010 and earlier

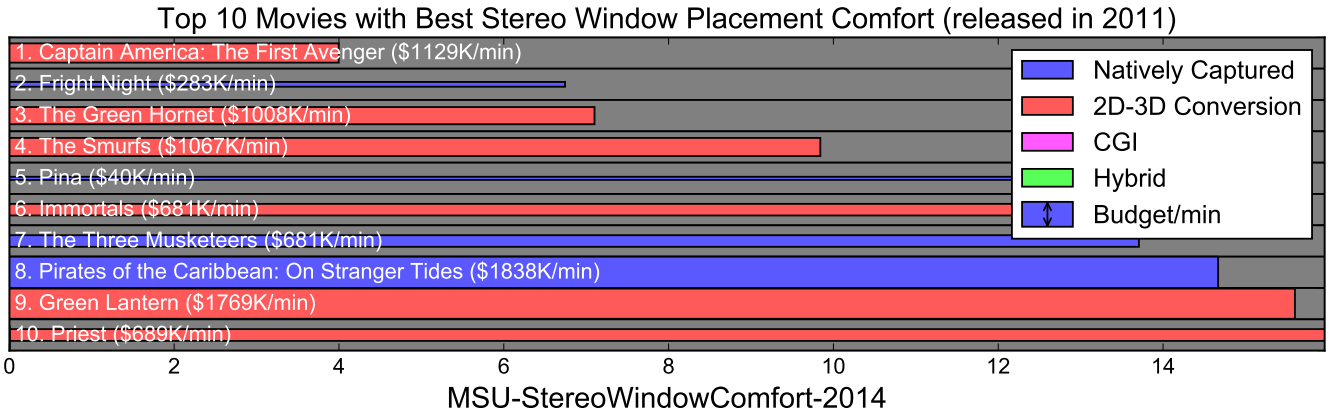


Figure 3.99: Diagram with top 10 best movies in terms of stereo window placement comfort released in 2011

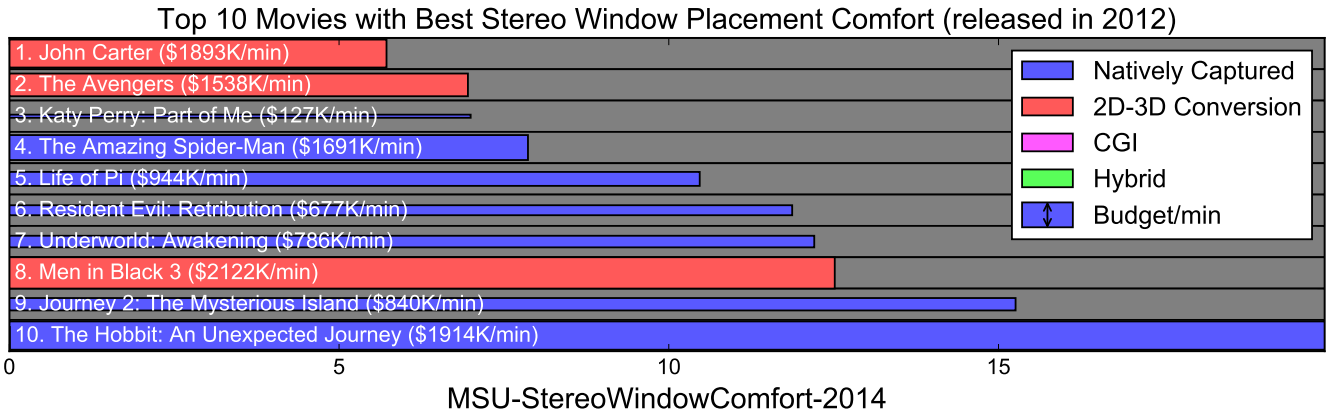


Figure 3.100: Diagram with top 10 best movies in terms of stereo window placement comfort released in 2012

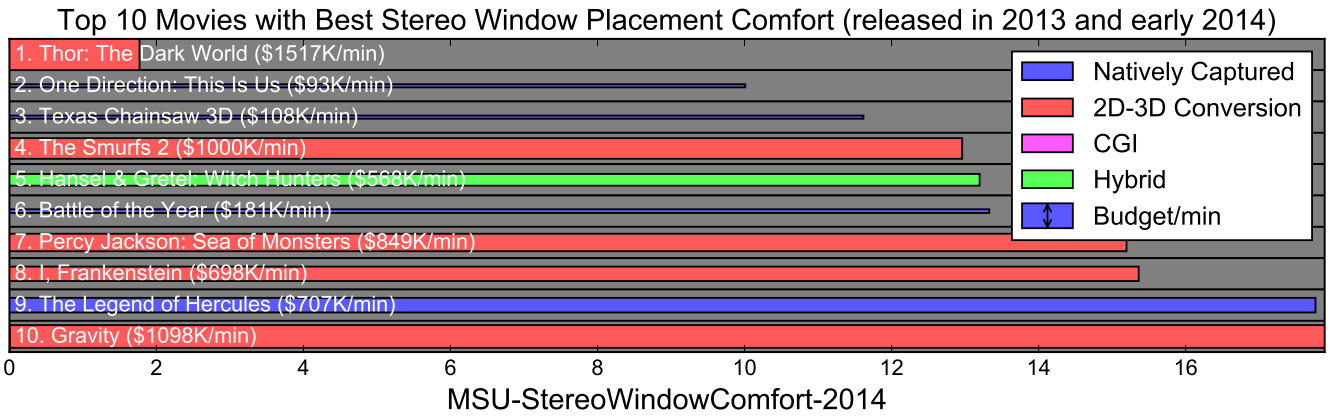


Figure 3.101: Diagram with top 10 best movies in terms of stereo window placement comfort released in 2013 and early 2014

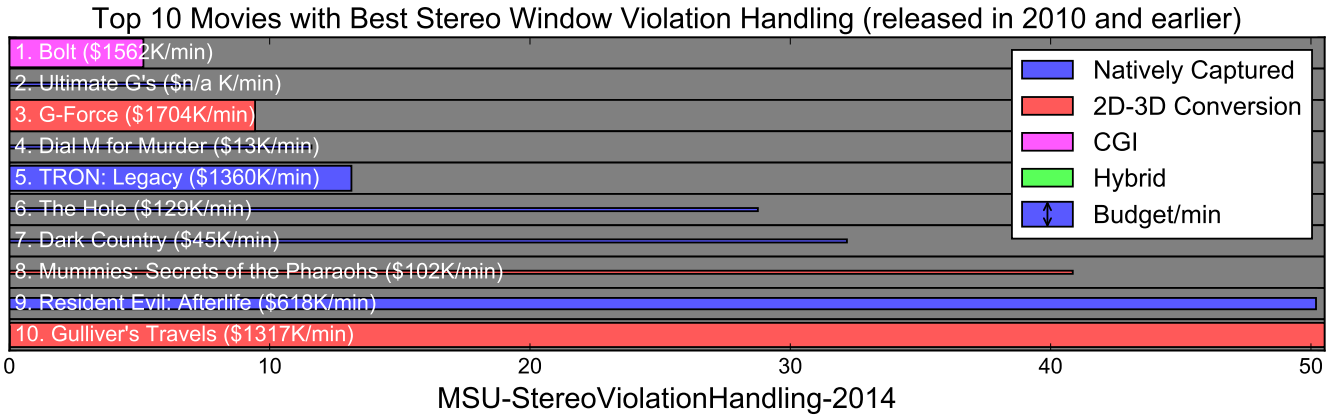


Figure 3.102: Diagram with top 10 best movies in terms of stereo window violation handling released in 2010 and earlier

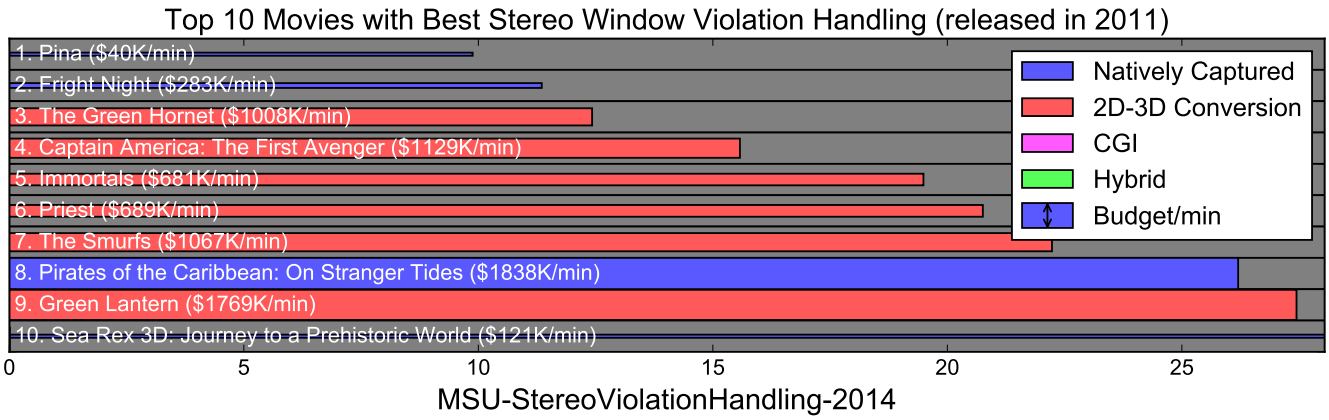


Figure 3.103: Diagram with top 10 best movies in terms of stereo window violation handling released in 2011

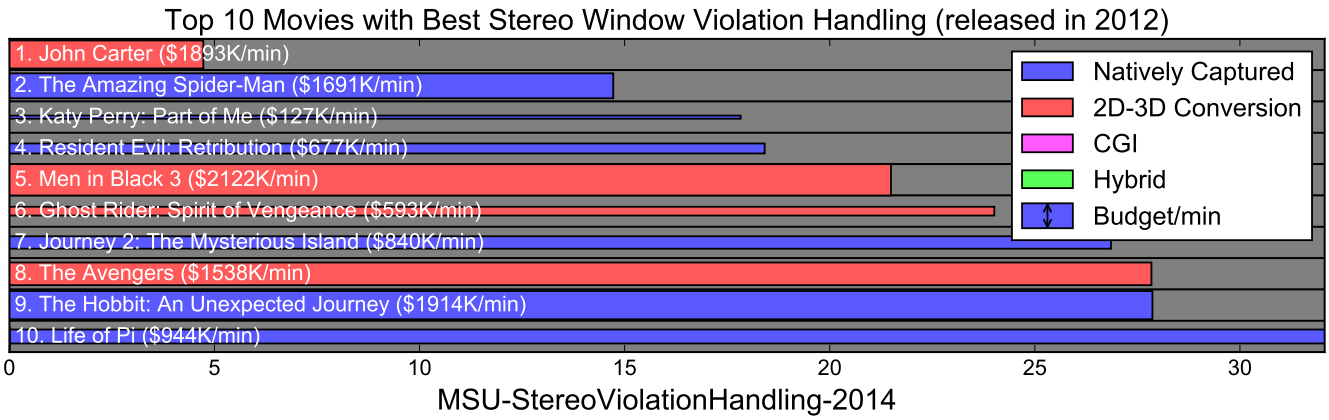


Figure 3.104: Diagram with top 10 best movies in terms of stereo window violation handling released in 2012

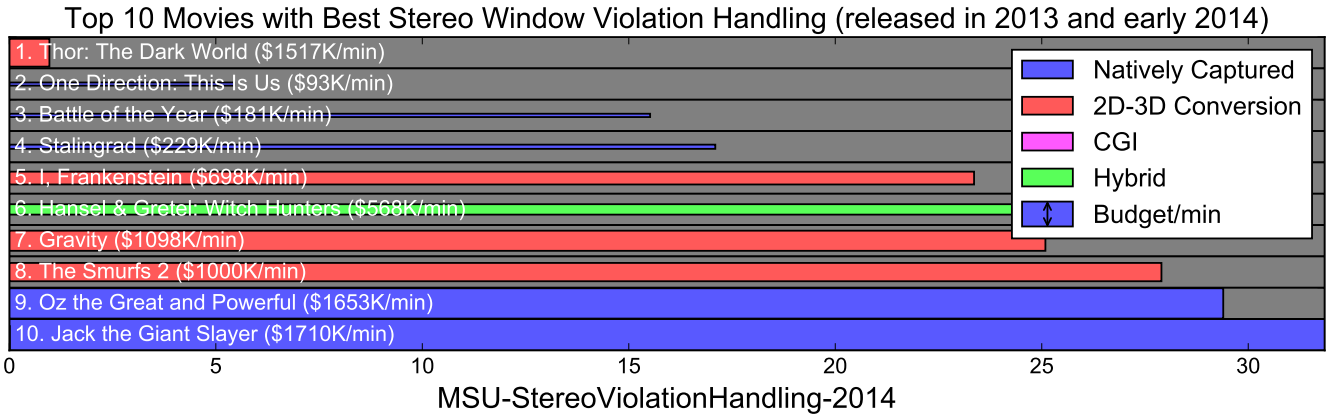


Figure 3.105: Diagram with top 10 best movies in terms of stereo window violation handling released in 2013 and early 2014

3.6.3 Overall Categories

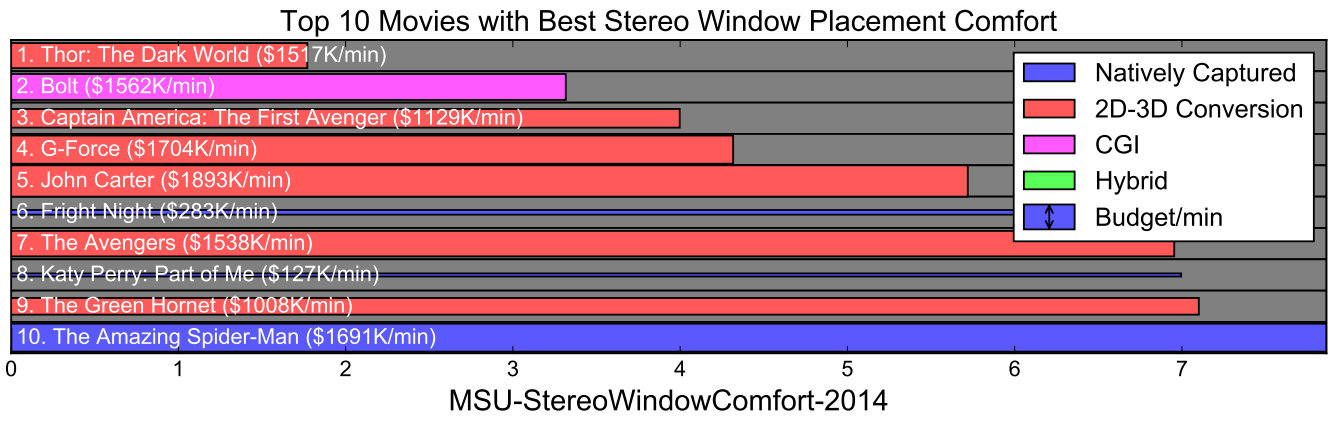


Figure 3.106: Diagram with top 10 best movies in terms of stereo window placement comfort

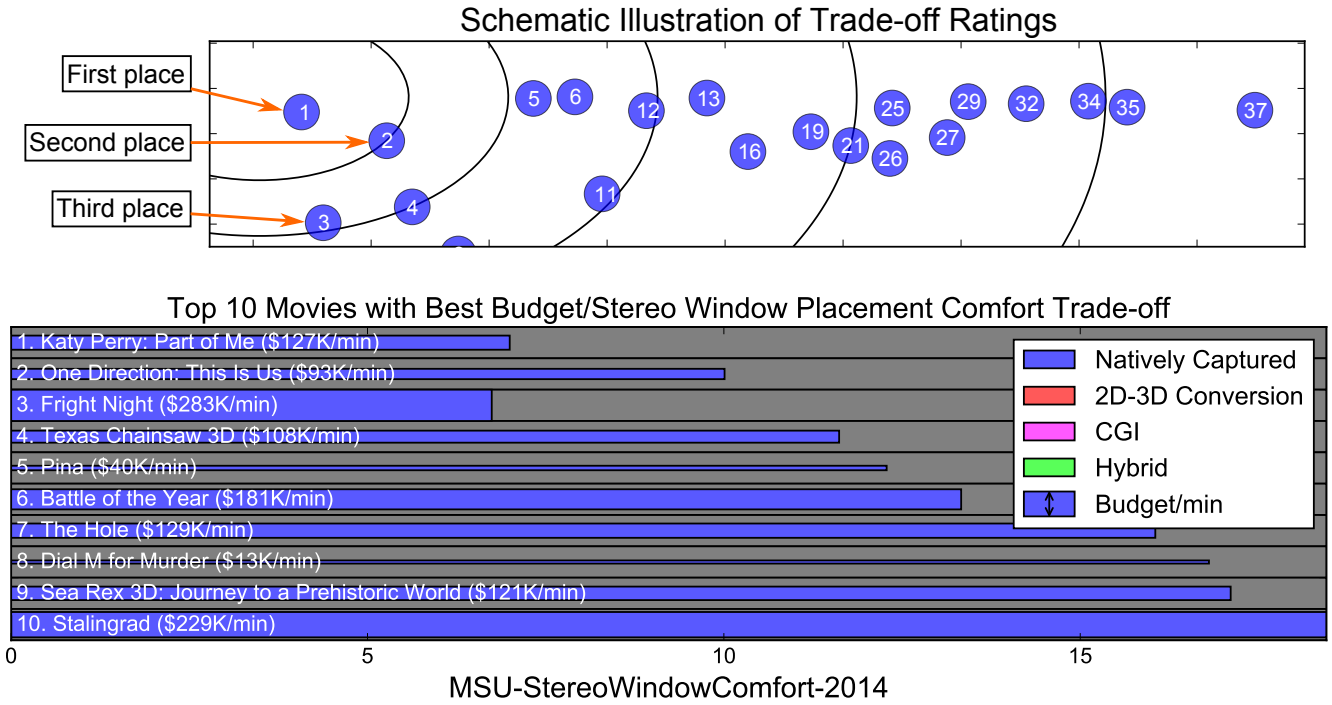


Figure 3.107: Diagram with top 10 best movies in terms of budget/stereo window placement comfort trade-off

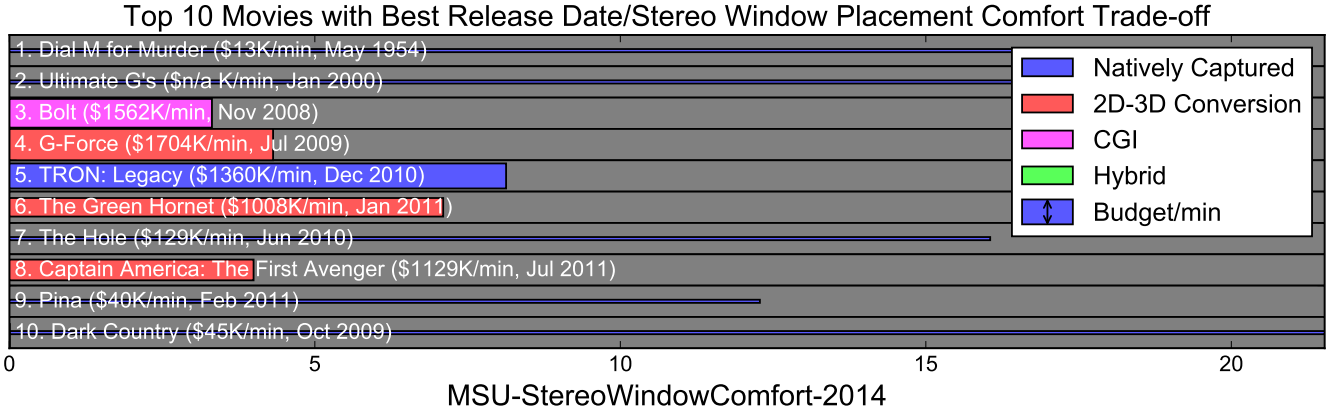


Figure 3.108: Diagram with top 10 best movies in terms of release date/stereo window placement comfort trade-off

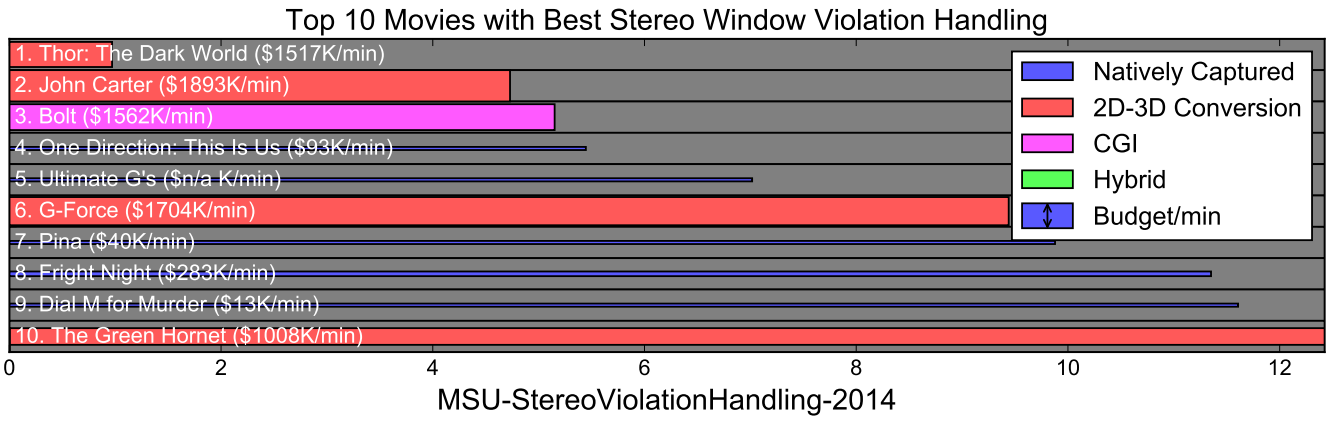


Figure 3.109: Diagram with top 10 best movies in terms of stereo window violation handling

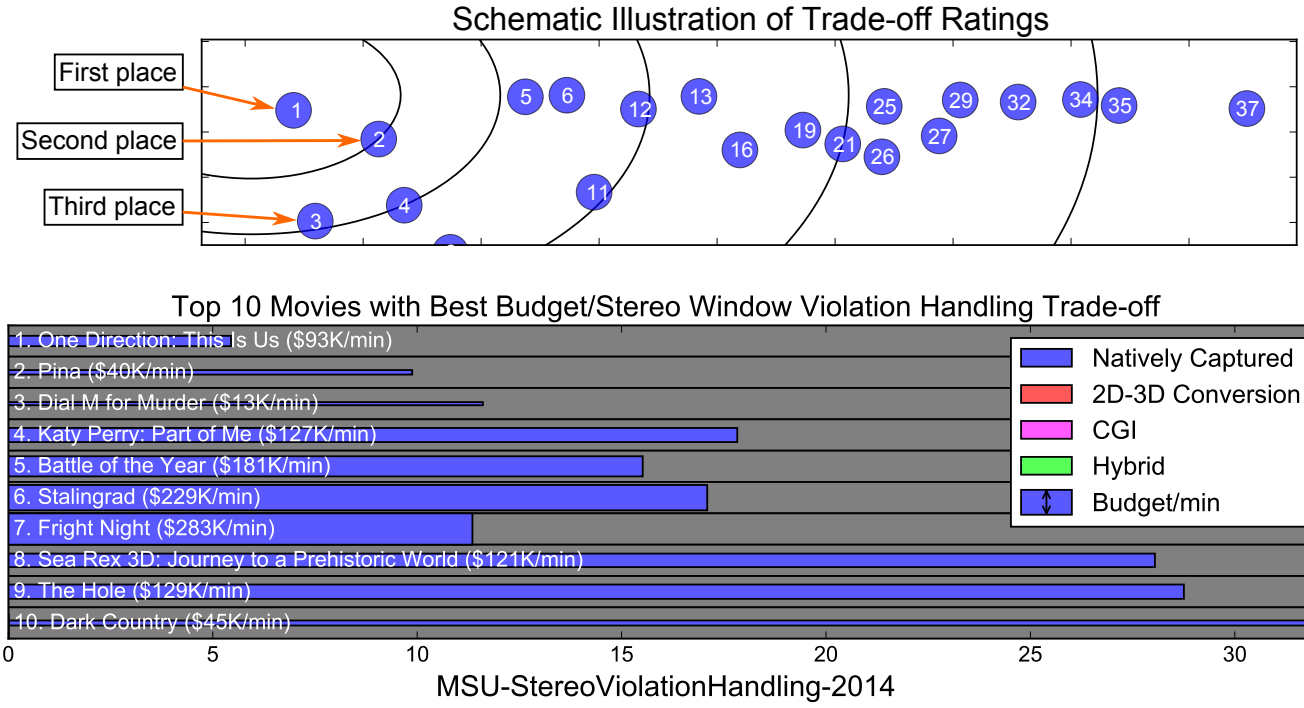


Figure 3.110: Diagram with top 10 best movies in terms of budget/stereo window violation handling trade-off

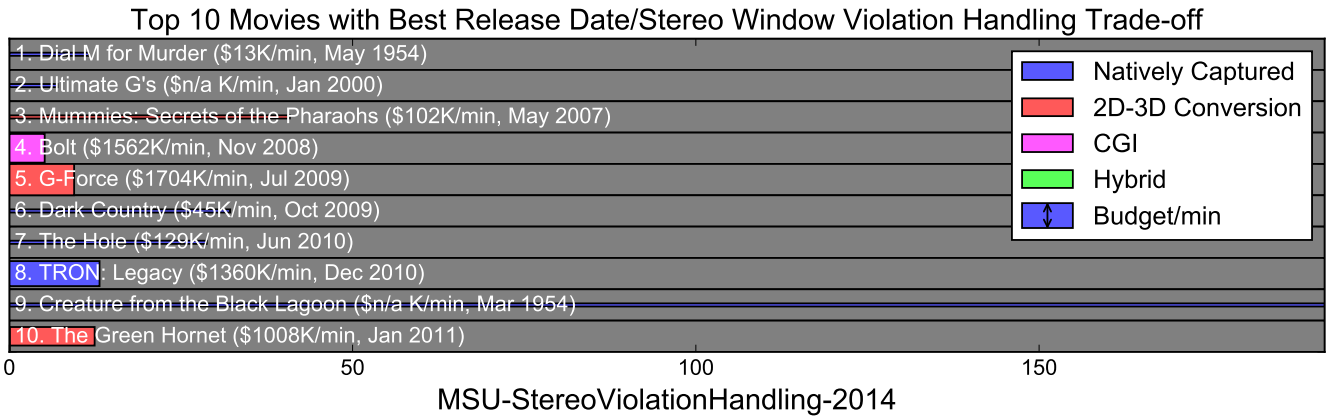


Figure 3.111: Diagram with top 10 best movies in terms of release date/stereo window violation handling trade-off

3.7 Overall Technical Quality

3.7.1 Disclaimer

1. Overall ratings in this section compare movies only in terms of **technical quality** measured using our metrics. A higher rank in a particular category doesn't necessarily mean a viewer will prefer that movie.

2. Movie ranks in this section are based on the average rating for categories that correspond to the following metrics: vertical parallax, scale/rotation mismatch, color mismatch and sharpness mismatch (only for natively captured movies).

3. Our technical-quality comparison of converted and captured S3D movies is generally unfair, as it fails to take into account problems specific to converted movies. Quantitative assessment of 2D-to-3D conversion problems is a more complicated task; previous reports analyze some of these problems [3,5]. Comparing converted S3D movies with each other is also less than entirely fair for the same reason. Another reason is that technical-quality differences between top converted movies are negligible when measured using our metrics, whereas perceived quality is mostly defined by specific 2D-to-3D conversion problems, which are beyond the scope of this report.

3.7.2 Budget Categories

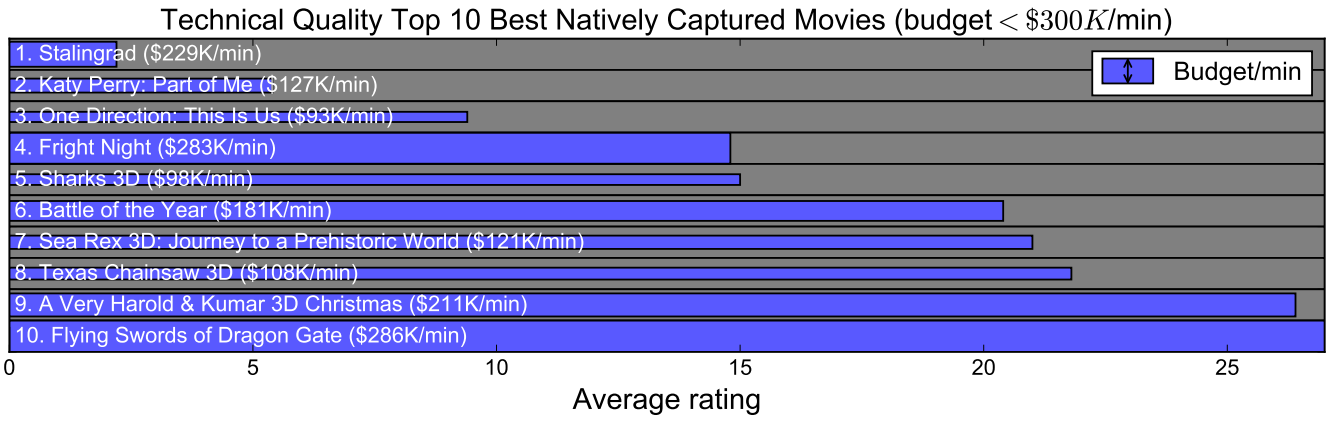


Figure 3.112: Diagram with overall top 10 best natively captured movies with budgets less than \$300K/minute

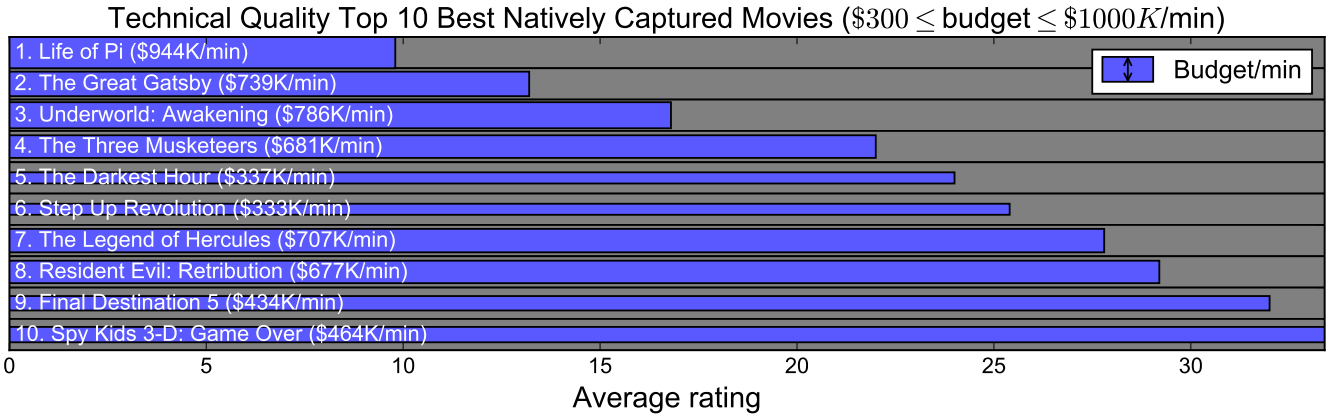


Figure 3.113: Diagram with overall top 10 best natively captured movies with budgets less than \$1000K/minute and more than \$300K/minute

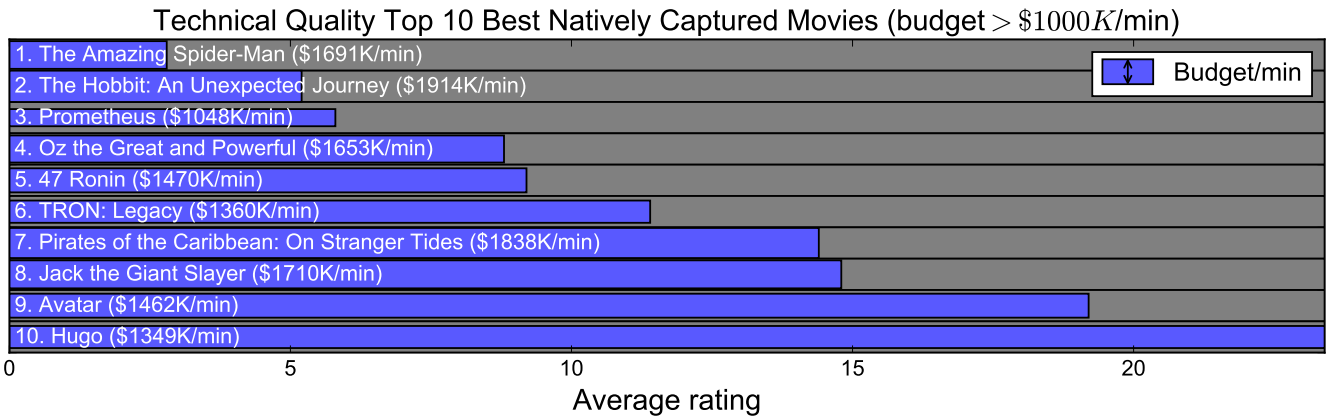


Figure 3.114: Diagram with overall top 10 best natively captured movies with budgets more than \$1000K/minute

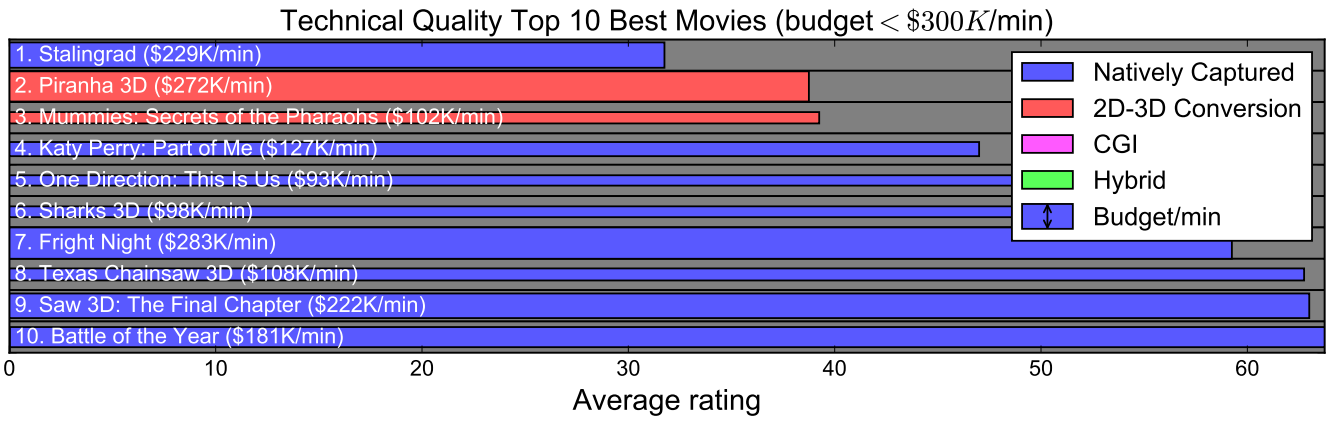


Figure 3.115: Diagram with overall top 10 best movies with budgets less than \$300K/minute

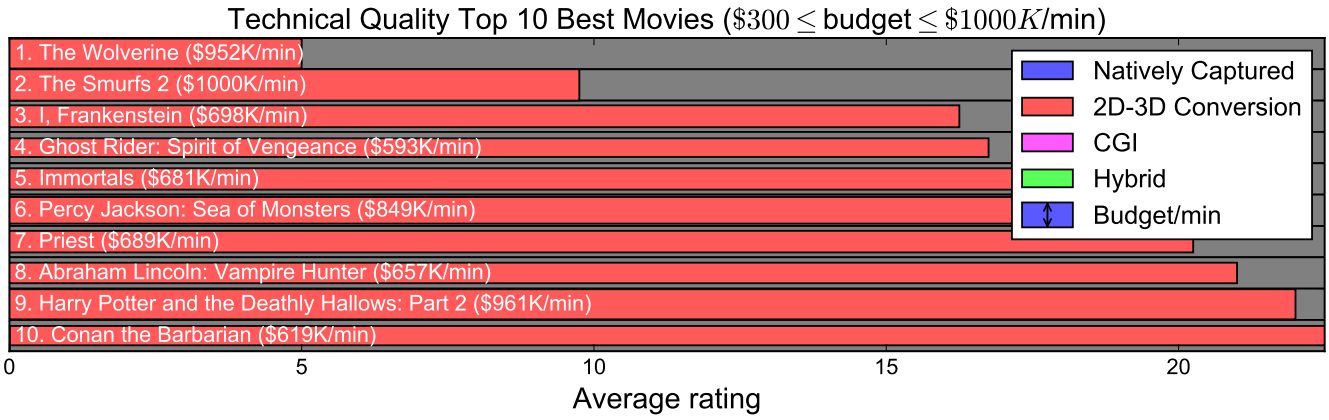


Figure 3.116: Diagram with overall top 10 best movies with budgets less than \$1000K/minute and more than \$300K/minute

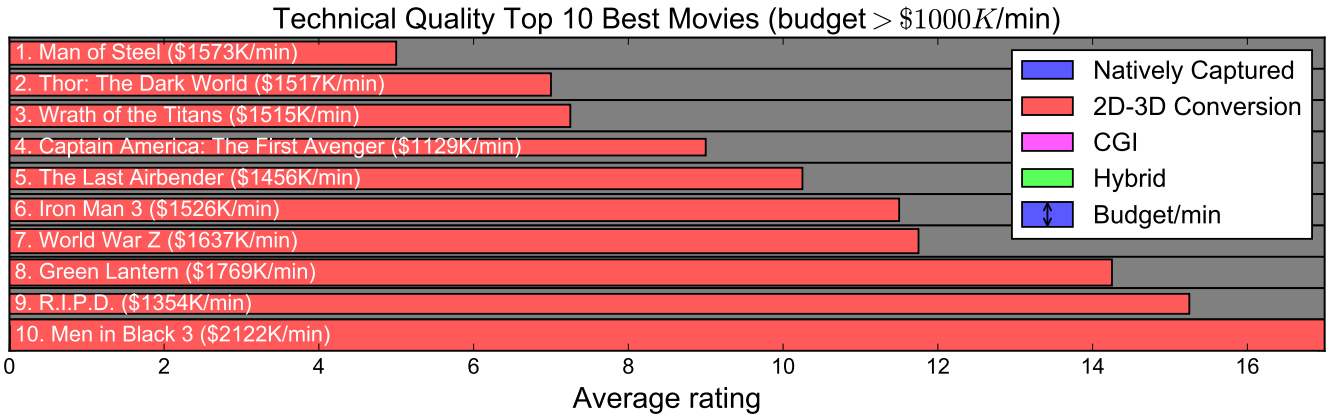


Figure 3.117: Diagram with overall top 10 best movies with budgets more than \$1000K/minute

3.7.3 Release Date Categories

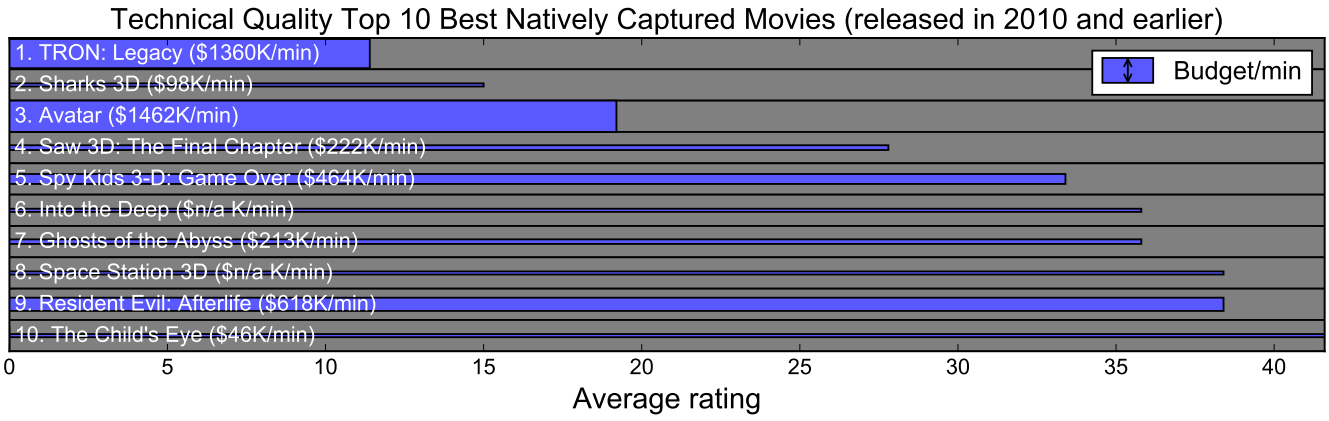


Figure 3.118: Diagram with overall top 10 best natively captured movies released in 2010 and earlier

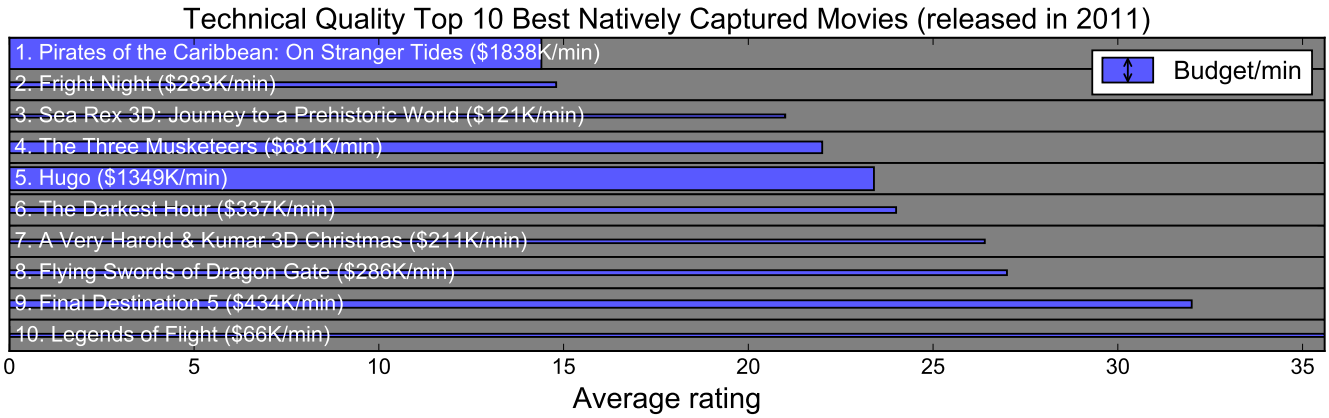


Figure 3.119: Diagram with overall top 10 best natively captured movies released in 2011

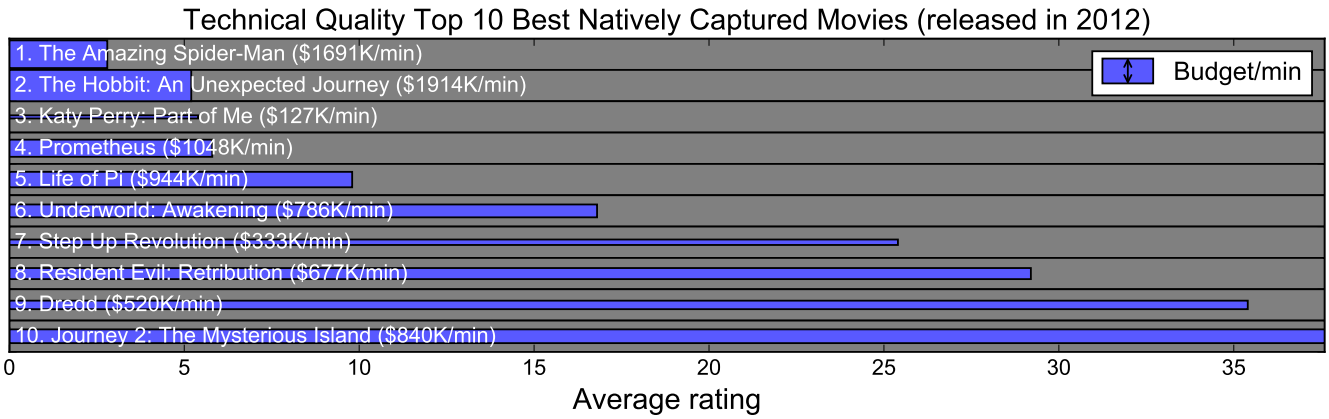


Figure 3.120: Diagram with overall top 10 best natively captured movies released in 2012

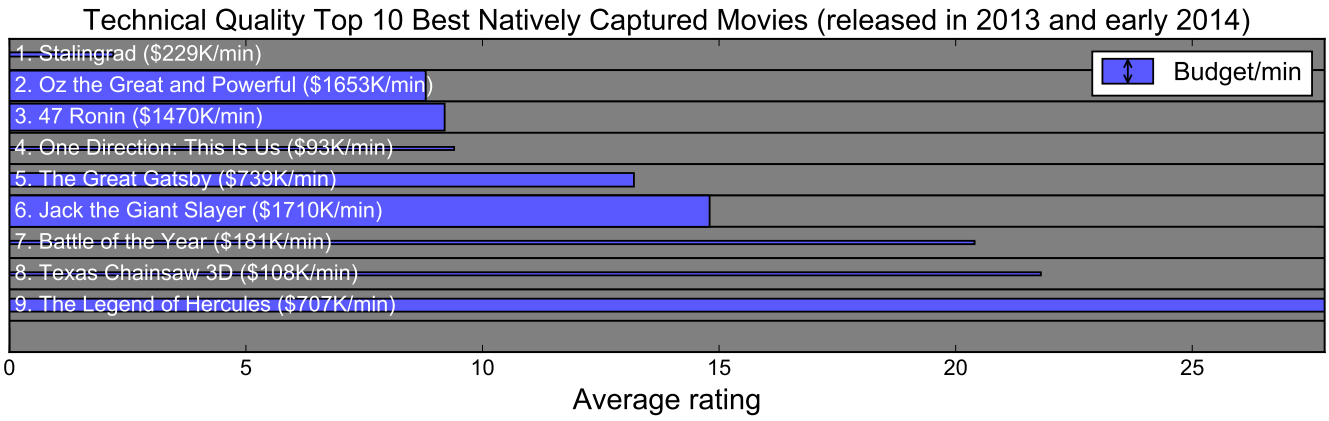


Figure 3.121: Diagram with overall top 10 best natively captured movies released in 2013 and early 2014

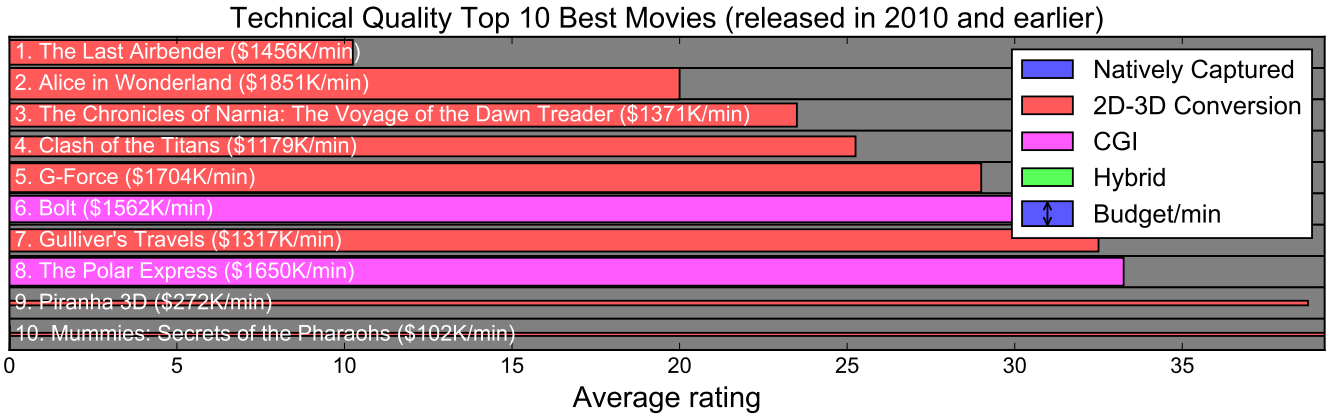


Figure 3.122: Diagram with overall top 10 best movies released in 2010 and earlier

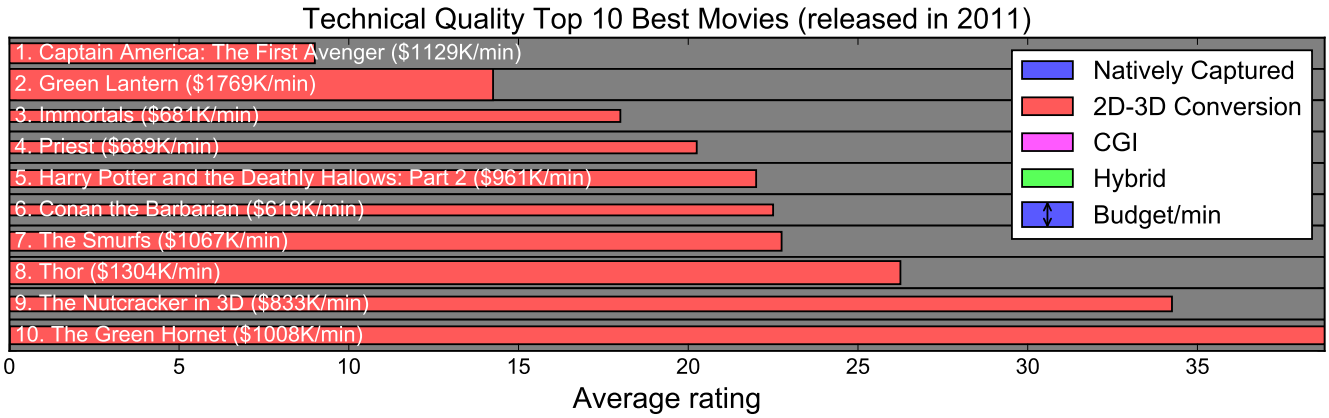


Figure 3.123: Diagram with overall top 10 best movies released in 2011

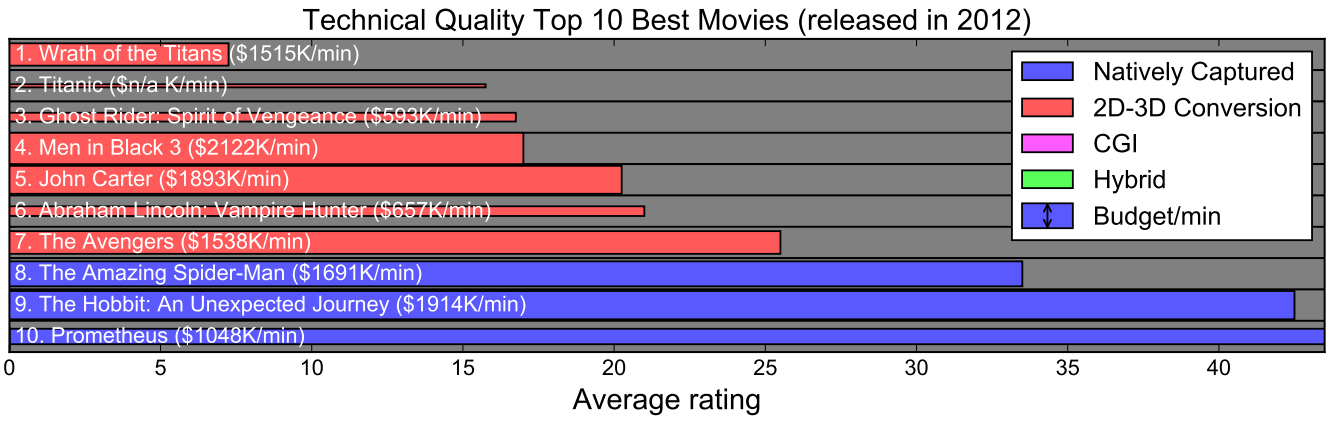


Figure 3.124: Diagram with overall top 10 best movies released in 2012

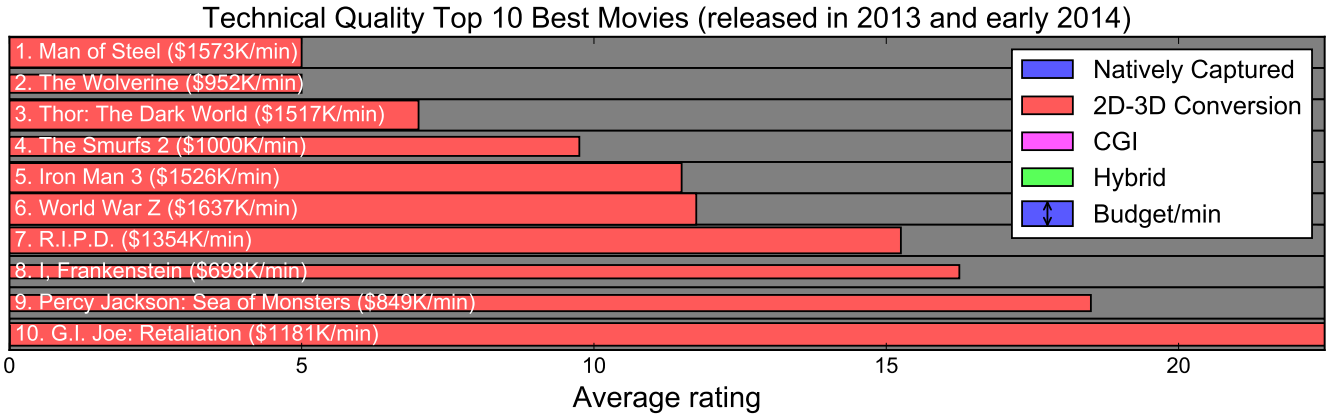


Figure 3.125: Diagram with overall top 10 best movies released in 2013 and early 2014

3.7.4 Overall Categories

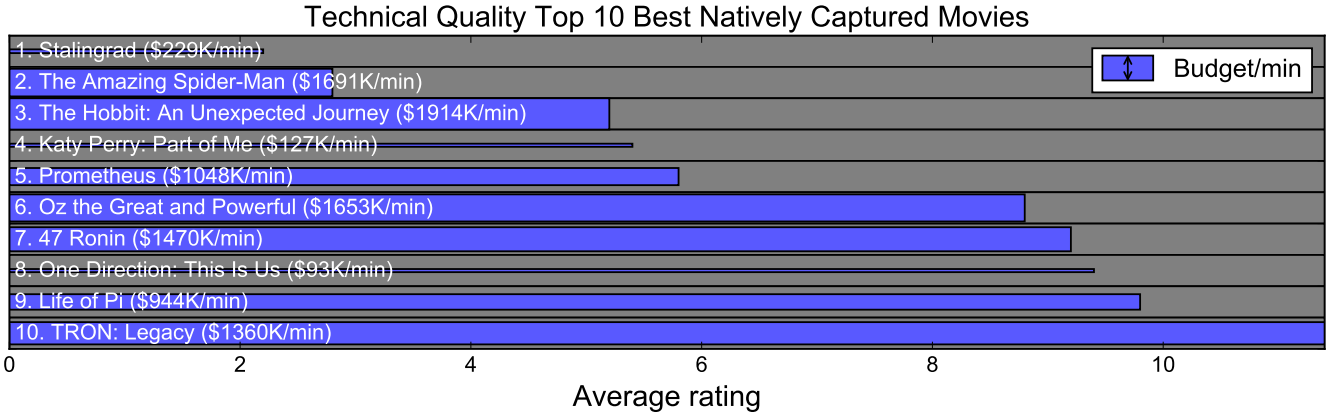


Figure 3.126: Diagram with overall top 10 best natively captured movies

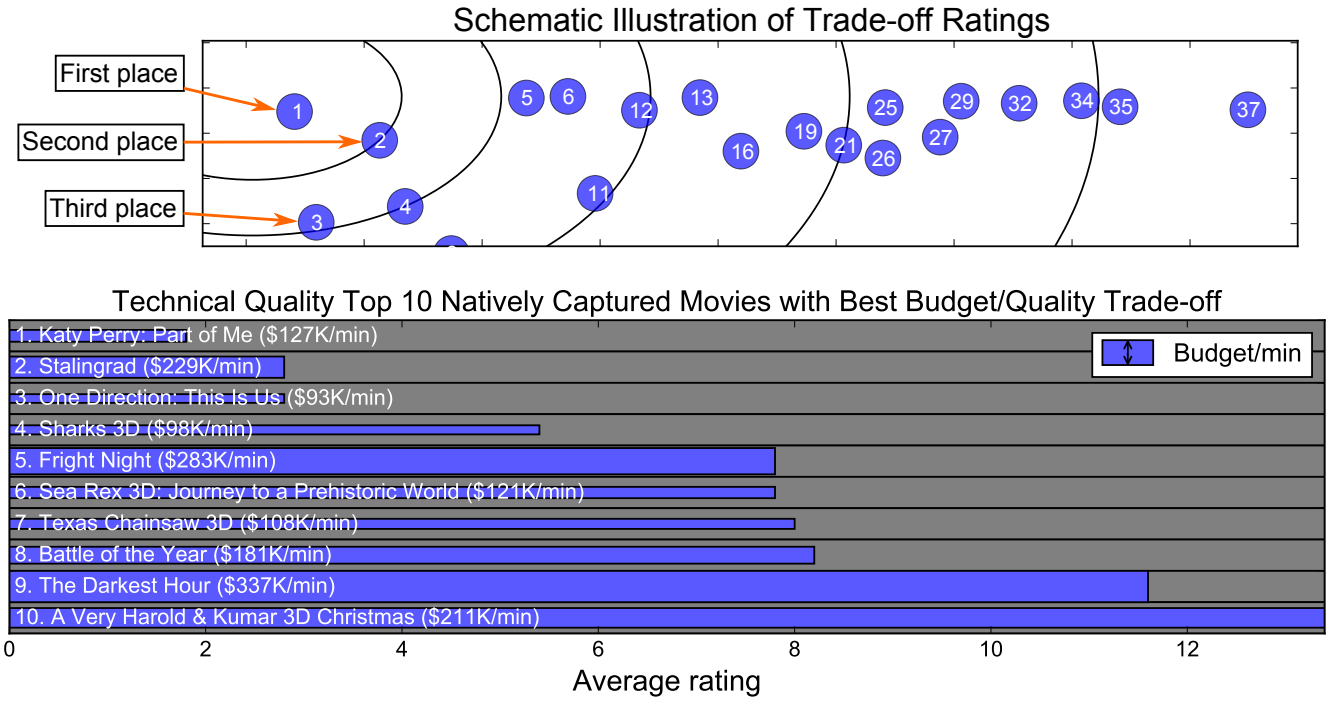


Figure 3.127: Diagram with overall top 10 best natively captured movies in terms of budget/quality trade-off

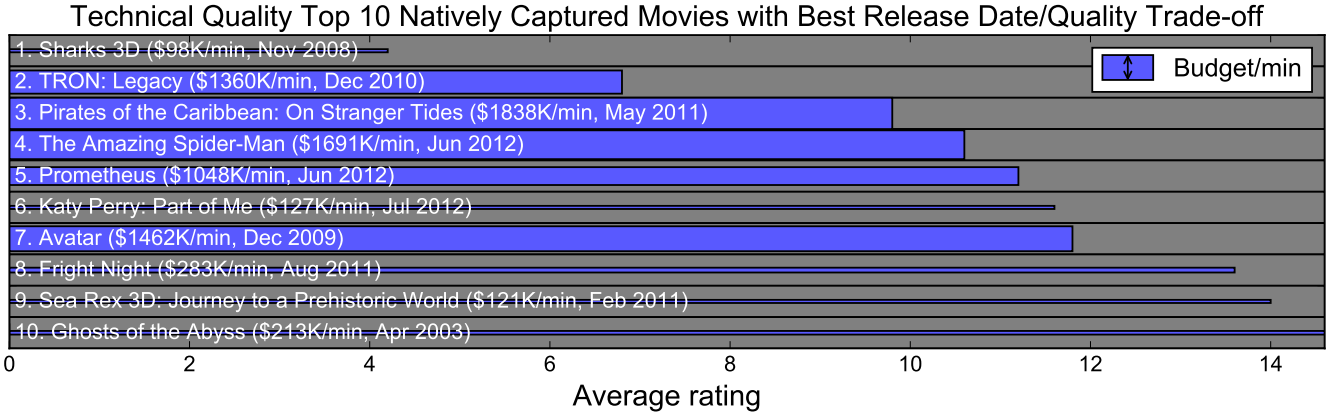


Figure 3.128: Diagram with overall top 10 best natively captured movies in terms of release date/quality trade-off

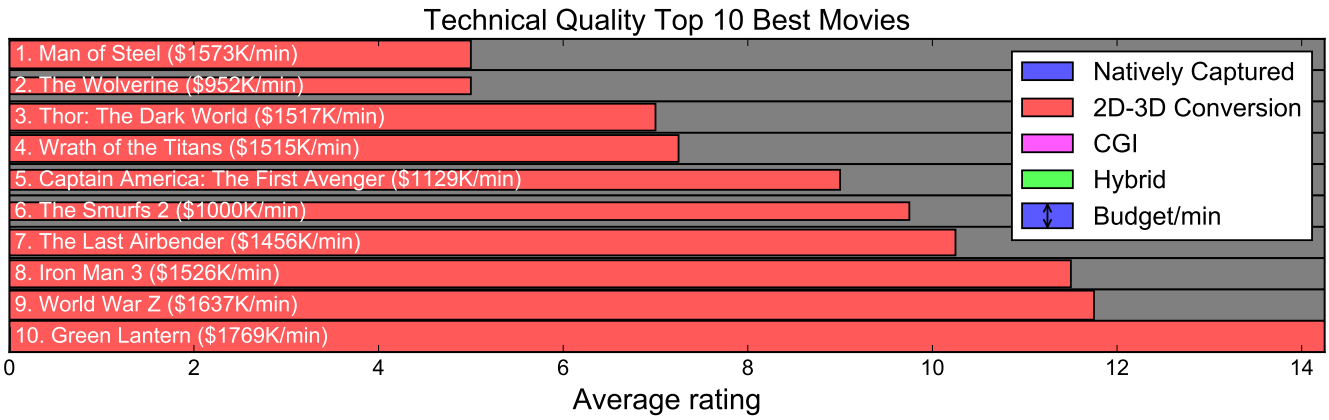


Figure 3.129: Diagram with overall top 10 best movies

Chapter 4

Movie Nominations

4.1 Disclaimer

1. This section presents a simple, concise overall movie ranking by number of nominations. We take into account only the top three places in each category; the previous section (Movie Ratings) presents more-detailed and more-comprehensive ratings.

2. Overall ratings in this section compare movies only in terms of **technical quality** measured using our metrics. A higher rank in a particular category doesn't necessarily mean a viewer will prefer that movie. Higher ranking of a movie in some category doesn't necessarily mean that this movie is indeed better for a viewer.

3. Our technical-quality comparison of converted and captured S3D movies is generally unfair, as it fails to take into account problems specific to converted movies. Quantitative assessment of 2D-to-3D conversion problems is a more complicated task; previous reports analyze some of these problems [3,5]. Comparing converted S3D movies with each other is also less than entirely fair for the same reason. Another reason is that technical-quality differences between top converted movies are negligible when measured using our metrics, whereas perceived quality is mostly defined by specific 2D-to-3D conversion problems, which are beyond the scope of this report.

4.2 Movies With Best Technical Quality

1. **Stalingrad** (Average Depth Budget: 0.64%)

   - **First Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**
   - **Third Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
   - **Third Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
   - **Third Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
   - **Second Place in Color Mismatch among Natively Captured Movies**
   - **First Place in Vertical Parallax among Natively Captured Movies**
   - **First Place in Scale Mismatch among Natively Captured Movies**
   - **First Place in Rotation Mismatch among Natively Captured Movies**
   - First Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)

- Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
- First Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
- First Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
- First Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)
- First Place in Color Mismatch (budget<$300K/min)
- First Place in Vertical Parallax (budget<$300K/min)
- First Place in Scale Mismatch (budget<$300K/min)
- Second Place in Rotation Mismatch (budget<$300K/min)
- First Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)
- Third Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
- First Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)
- First Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)
- First Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

2. **Katy Perry: Part of Me** (Average Depth Budget: 0.35%)

- **Second Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
- **First Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
- **Second Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Sharpness Mismatch among Natively Captured Movies**
- **Third Place in Vertical Parallax among Natively Captured Movies**
- First Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Vertical Parallax among Natively Captured Movies (released in 2012)
- Third Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)
- Third Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

3. **The Amazing Spiderman** (Average Depth Budget: 0.56%)

- **First Place in Color Mismatch among Natively Captured Movies**
- **Third Place in Scale Mismatch among Natively Captured Movies**

- **Second Place in Rotation Mismatch among Natively Captured Movies**
- Third Place in Color Mismatch (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Vertical Parallax among Natively Captured Movies (released in 2012)
- Second Place in Scale Mismatch among Natively Captured Movies (released in 2012)
- First Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
- First Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)
- Second Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
- Second Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
- First Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

4. **One Direction: This Is Us** (Average Depth Budget: 0.52%)

   - **Third Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**
   - **First Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
   - **Second Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
   - **Third Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**
   - **First Place in Sharpness Mismatch among Natively Captured Movies**
   - First Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
   - Third Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
   - First Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
   - Third Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)

5. **The Wolverine** (2D-3D Conversion, Average Depth Budget: 1.36%)

   - **Third Place in Vertical Parallax**
   - **First Place in Scale Mismatch**
   - **First Place in Rotation Mismatch**
   - Second Place in Vertical Parallax (released in 2013 and early 2014)
   - First Place in Scale Mismatch (released in 2013 and early 2014)
   - First Place in Rotation Mismatch (released in 2013 and early 2014)
   - First Place in Vertical Parallax ($300<budget<$1000K/min)
   - First Place in Scale Mismatch ($300<budget<$1000K/min)
   - First Place in Rotation Mismatch ($300<budget<$1000K/min)

6. **The Last Airbender** (2D-3D Conversion, Average Depth Budget: 0.24%)

- **First Place in Vertical Parallax**
- **Second Place in Scale Mismatch**
- **Second Place in Rotation Mismatch**
- First Place in Vertical Parallax (released in 2010 and earlier)
- First Place in Scale Mismatch (released in 2010 and earlier)
- First Place in Rotation Mismatch (released in 2010 and earlier)
- First Place in Vertical Parallax (budget>$1000K/min)
- First Place in Scale Mismatch (budget>$1000K/min)
- First Place in Rotation Mismatch (budget>$1000K/min)

7. **The Hobbit: An Unexpected Journey** (Average Depth Budget: 0.82%)

- **Third Place in Rotation Mismatch among Natively Captured Movies**
- Second Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Scale Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
- Third Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
- Third Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

8. **Life of Pi** (Average Depth Budget: 0.74%)

- **Third Place in Sharpness Mismatch among Natively Captured Movies**
- Third Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- First Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

9. **Sharks 3D** (Average Depth Budget: 2.27%)

- **Third Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**
- **First Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
- **First Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**
- Second Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Second Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)

- First Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Third Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

10. **Prometheus** (Average Depth Budget: 0.87%)

    - **Second Place in Vertical Parallax among Natively Captured Movies**
    - **Second Place in Scale Mismatch among Natively Captured Movies**
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2012)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2012)
    - First Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
    - First Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
    - Third Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

11. **Man of Steel** (2D-3D Conversion, Average Depth Budget: 0.84%)

    - **Second Place in Vertical Parallax**
    - Second Place in Color Mismatch (released in 2013 and early 2014)
    - First Place in Vertical Parallax (released in 2013 and early 2014)
    - Second Place in Rotation Mismatch (released in 2013 and early 2014)
    - Third Place in Color Mismatch (budget>$1000K/min)
    - Second Place in Vertical Parallax (budget>$1000K/min)
    - Third Place in Rotation Mismatch (budget>$1000K/min)

12. **TRON: Legacy** (Average Depth Budget: 0.75%)

    - **Third Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **Third Place in Color Mismatch among Natively Captured Movies**
    - First Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - First Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)
    - Second Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
    - Second Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)

13. **Wrath of the Titans** (2D-3D Conversion, Average Depth Budget: 0.73%)

    - **Third Place in Rotation Mismatch**
    - First Place in Vertical Parallax (released in 2012)
    - Third Place in Scale Mismatch (released in 2012)
    - First Place in Rotation Mismatch (released in 2012)
    - Third Place in Vertical Parallax (budget>$1000K/min)
    - Second Place in Rotation Mismatch (budget>$1000K/min)

14. **The Smurfs 2** (2D-3D Conversion, Average Depth Budget: 1.09%)

    - Third Place in Vertical Parallax (released in 2013 and early 2014)
    - Third Place in Scale Mismatch (released in 2013 and early 2014)
    - Second Place in Vertical Parallax ($300<budget<$1000K/min)
    - Second Place in Scale Mismatch ($300<budget<$1000K/min)
    - Second Place in Rotation Mismatch ($300<budget<$1000K/min)

15. **Fright Night** (Average Depth Budget: 1.08%)

    - First Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - First Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Scale Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)

16. **Saw 3D: The Final Chapter** (Average Depth Budget: 1.26%)

    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Scale Mismatch (budget<$300K/min)
    - Second Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)

17. **Thor: The Dark World** (2D-3D Conversion, Average Depth Budget: 1.13%)

    - **Third Place in Scale Mismatch**
    - Second Place in Scale Mismatch (released in 2013 and early 2014)
    - Third Place in Rotation Mismatch (released in 2013 and early 2014)
    - Second Place in Scale Mismatch (budget>$1000K/min)

18. **Immortals** (2D-3D Conversion, Average Depth Budget: 0.77%)

    - **Third Place in Color Mismatch**
    - Second Place in Color Mismatch (released in 2011)
    - Third Place in Vertical Parallax (released in 2011)
    - Second Place in Color Mismatch ($300<budget<$1000K/min)

19. **Pirates of the Caribbean: On Stranger Tides** (Average Depth Budget: 0.94%)

    - Second Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2011)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2011)
    - First Place in Rotation Mismatch among Natively Captured Movies (released in 2011)

20. **Into the Deep** (Average Depth Budget: 3.74%)

    - **Second Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**
    - Third Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)

21. **The Great Gatsby** (Average Depth Budget: 1.20%)

    - Third Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

22. **Mummies: Secrets of the Pharaohs** (2D-3D Conversion, Average Depth Budget: 0.86%)

    - Second Place in Color Mismatch (budget<$300K/min)
    - Third Place in Vertical Parallax (budget<$300K/min)
    - Second Place in Scale Mismatch (budget<$300K/min)
    - Third Place in Rotation Mismatch (budget<$300K/min)

23. **Captain America: The First Avenger** (2D-3D Conversion, Average Depth Budget: 0.83%)

    - First Place in Vertical Parallax (released in 2011)
    - First Place in Scale Mismatch (released in 2011)
    - First Place in Rotation Mismatch (released in 2011)

24. **The Three Musketeers** (Average Depth Budget: 0.77%)

    - Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Scale Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

25. **Men in Black 3** (2D-3D Conversion, Average Depth Budget: 1.12%)

    - First Place in Scale Mismatch (released in 2012)
    - Second Place in Rotation Mismatch (released in 2012)
    - Third Place in Scale Mismatch (budget>$1000K/min)

26. **47 Ronin** (Average Depth Budget: 0.79%)

    - Second Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)

- Third Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
- Third Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)

27. **Underworld: Awakening** (Average Depth Budget: 0.69%)

    - Second Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - Third Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
    - Third Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

28. **Clash of the Titans** (2D-3D Conversion, Average Depth Budget: 0.66%)

    - **Second Place in Color Mismatch**
    - First Place in Color Mismatch (released in 2010 and earlier)
    - First Place in Color Mismatch (budget>$1000K/min)

29. **Green Lantern** (2D-3D Conversion, Average Depth Budget: 0.67%)

    - Second Place in Vertical Parallax (released in 2011)
    - Second Place in Scale Mismatch (released in 2011)
    - Second Place in Rotation Mismatch (released in 2011)

30. **The Chronicles of Narnia: The Voyage of the Dawn Treader** (2D-3D Conversion, Average Depth Budget: 0.78%)

    - Second Place in Color Mismatch (released in 2010 and earlier)
    - Third Place in Vertical Parallax (released in 2010 and earlier)
    - Third Place in Scale Mismatch (released in 2010 and earlier)

31. **Piranha 3D** (2D-3D Conversion, Average Depth Budget: 0.84%)

    - Third Place in Color Mismatch (budget<$300K/min)
    - Second Place in Vertical Parallax (budget<$300K/min)
    - First Place in Rotation Mismatch (budget<$300K/min)

32. **Titanic** (2D-3D Conversion, Average Depth Budget: 1.55%)

    - Second Place in Color Mismatch (released in 2012)
    - Second Place in Scale Mismatch (released in 2012)
    - Third Place in Rotation Mismatch (released in 2012)

33. **Alice in Wonderland** (2D-3D Conversion, Average Depth Budget: 1.24%)

    - Third Place in Color Mismatch (released in 2010 and earlier)
    - Second Place in Scale Mismatch (released in 2010 and earlier)

- Second Place in Rotation Mismatch (released in 2010 and earlier)

34. **Priest** (2D-3D Conversion, Average Depth Budget: 0.78%)

    - **First Place in Color Mismatch**
    - First Place in Color Mismatch (released in 2011)
    - First Place in Color Mismatch ($300<budget<$1000K/min)

35. **Spy Kids 3-D: Game Over** (Average Depth Budget: 2.40%)

    - **Second Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**
    - Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)

36. **Oz the Great and Powerful** (Average Depth Budget: 1.05%)

    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
    - Second Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)

37. **Iron Man 3** (2D-3D Conversion, Average Depth Budget: 1.11%)

    - First Place in Color Mismatch (released in 2013 and early 2014)
    - Second Place in Color Mismatch (budget>$1000K/min)

38. **Ghost Rider: Spirit of Vengeance** (2D-3D Conversion, Average Depth Budget: 0.38%)

    - First Place in Color Mismatch (released in 2012)
    - Third Place in Rotation Mismatch ($300<budget<$1000K/min)

39. **Hugo** (Average Depth Budget: 1.57%)

    - Third Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Vertical Parallax among Natively Captured Movies (released in 2011)

40. **Jack the Giant Slayer** (Average Depth Budget: 0.84%)

    - Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Third Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)

41. **Dial M for Murder** (Average Depth Budget: 2.02%)
    - **First Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**
42. **Abraham Lincoln: Vampire Hunter** (2D-3D Conversion, Average Depth Budget: 1.12%)
    - Third Place in Vertical Parallax (released in 2012)
    - Third Place in Vertical Parallax ($300<budget<$1000K/min)
43. **Avatar** (Average Depth Budget: 1.69%)
    - **Third Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)
44. **Space Station 3D** (Average Depth Budget: 2.06%)
    - **Second Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**
    - **Second Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**
45. **Harry Potter and the Deathly Hallows: Part 2** (2D-3D Conversion, Average Depth Budget: 0.47%)
    - Third Place in Color Mismatch (released in 2011)
    - Third Place in Color Mismatch ($300<budget<$1000K/min)
46. **Conan the Barbarian** (2D-3D Conversion, Average Depth Budget: 0.50%)
    - Third Place in Scale Mismatch (released in 2011)
    - Third Place in Rotation Mismatch (released in 2011)
47. **A Very Harold & Kumar 3D Christmas** (Average Depth Budget: 0.89%)
    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2011)
    - Third Place in Rotation Mismatch among Natively Captured Movies (released in 2011)
48. **John Carter** (2D-3D Conversion, Average Depth Budget: 1.17%)
    - Second Place in Vertical Parallax (released in 2012)
49. **Battle of the Year** (Average Depth Budget: 0.91%)

- Third Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)

50. **Percy Jackson: Sea of Monsters** (2D-3D Conversion, Average Depth Budget: 1.18%)
    - Third Place in Color Mismatch (released in 2013 and early 2014)
51. **Ghosts of the Abyss** (Average Depth Budget: 2.56%)
    - **Third Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
52. **Cirque du Soleil: Journey of Man** (Average Depth Budget: 1.50%)
    - **Third Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**
53. **Step Up Revolution** (Average Depth Budget: 1.15%)
    - Third Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
54. **Sea Rex 3D: Journey to a Prehistoric World** (Average Depth Budget: 1.24%)
    - Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
55. **Galapagos: The Enchanted Voyage** (Average Depth Budget: 2.57%)
    - **First Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
56. **Bolt** (CGI, Average Depth Budget: 1.61%)
    - Second Place in Vertical Parallax (released in 2010 and earlier)
57. **Creature from the Black Lagoon** (Average Depth Budget: 3.18%)
    - **Second Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
58. **I, Frankenstein** (2D-3D Conversion, Average Depth Budget: 0.96%)
    - Third Place in Scale Mismatch ($300<budget<$1000K/min)
59. **The Polar Express** (CGI, Average Depth Budget: 1.54%)
    - Third Place in Rotation Mismatch (released in 2010 and earlier)
60. **Resident Evil: Retribution** (Average Depth Budget: 0.87%)
    - Second Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

61. **My Bloody Valentine** (Average Depth Budget: 1.69%)

    - Third Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)

4.3 Natively Captured Movies With Best Technical Quality

1. **Stalingrad** (Average Depth Budget: 0.64%)

    - **First Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**
    - **Third Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
    - **Third Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
    - **Third Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
    - **Second Place in Color Mismatch among Natively Captured Movies**
    - **First Place in Vertical Parallax among Natively Captured Movies**
    - **First Place in Scale Mismatch among Natively Captured Movies**
    - **First Place in Rotation Mismatch among Natively Captured Movies**
    - First Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - First Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - First Place in Color Mismatch (budget<$300K/min)
    - First Place in Vertical Parallax (budget<$300K/min)
    - First Place in Scale Mismatch (budget<$300K/min)
    - Second Place in Rotation Mismatch (budget<$300K/min)
    - First Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)
    - Third Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
    - First Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)
    - First Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)
    - First Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

2. **Katy Perry: Part of Me** (Average Depth Budget: 0.35%)

    - **Second Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**

- **Second Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
- **First Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
- **Second Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Sharpness Mismatch among Natively Captured Movies**
- **Third Place in Vertical Parallax among Natively Captured Movies**
- First Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Vertical Parallax among Natively Captured Movies (released in 2012)
- Third Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)
- Third Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

3. **The Amazing Spiderman** (Average Depth Budget: 0.56%)

- **First Place in Color Mismatch among Natively Captured Movies**
- **Third Place in Scale Mismatch among Natively Captured Movies**
- **Second Place in Rotation Mismatch among Natively Captured Movies**
- Third Place in Color Mismatch (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Vertical Parallax among Natively Captured Movies (released in 2012)
- Second Place in Scale Mismatch among Natively Captured Movies (released in 2012)
- First Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
- First Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)
- Second Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
- Second Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
- First Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

4. **One Direction: This Is Us** (Average Depth Budget: 0.52%)

- **Third Place in Color Mismatch/Budget Trade-off among Natively Captured Movies**
- **First Place in Sharpness Mismatch/Budget Trade-off among Natively Captured Movies**
- **Second Place in Vertical Parallax/Budget Trade-off among Natively Captured Movies**
- **Third Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**

- **First Place in Sharpness Mismatch among Natively Captured Movies**
- First Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
- Third Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
- First Place in Sharpness Mismatch among Natively Captured Movies (budget<$300K/min)
- Third Place in Vertical Parallax among Natively Captured Movies (budget<$300K/min)

5. **The Hobbit: An Unexpected Journey** (Average Depth Budget: 0.82%)

- **Third Place in Rotation Mismatch among Natively Captured Movies**
- Second Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Scale Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Rotation Mismatch among Natively Captured Movies (released in 2012)
- Third Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
- Third Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
- Third Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

6. **Life of Pi** (Average Depth Budget: 0.74%)

- **Third Place in Sharpness Mismatch among Natively Captured Movies**
- Third Place in Color Mismatch among Natively Captured Movies (released in 2012)
- Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2012)
- First Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- First Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
- Second Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

7. **Sharks 3D** (Average Depth Budget: 2.27%)

- **Third Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**
- **First Place in Scale Mismatch/Budget Trade-off among Natively Captured Movies**
- **First Place in Rotation Mismatch/Budget Trade-off among Natively Captured Movies**
- Second Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Second Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)
- First Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)
- Third Place in Rotation Mismatch among Natively Captured Movies (budget<$300K/min)

8. **Prometheus** (Average Depth Budget: 0.87%)

    - **Second Place in Vertical Parallax among Natively Captured Movies**
    - **Second Place in Scale Mismatch among Natively Captured Movies**
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2012)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2012)
    - First Place in Vertical Parallax among Natively Captured Movies (budget>$1000K/min)
    - First Place in Scale Mismatch among Natively Captured Movies (budget>$1000K/min)
    - Third Place in Rotation Mismatch among Natively Captured Movies (budget>$1000K/min)

9. **TRON: Legacy** (Average Depth Budget: 0.75%)

    - **Third Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **Third Place in Color Mismatch among Natively Captured Movies**
    - First Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - First Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)
    - Second Place in Color Mismatch among Natively Captured Movies (budget>$1000K/min)
    - Second Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)

10. **Fright Night** (Average Depth Budget: 1.08%)

    - First Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - First Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Scale Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2011)
    - Second Place in Color Mismatch among Natively Captured Movies (budget<$300K/min)

11. **Saw 3D: The Final Chapter** (Average Depth Budget: 1.26%)

    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Scale Mismatch (budget<$300K/min)
    - Second Place in Scale Mismatch among Natively Captured Movies (budget<$300K/min)

12. **Pirates of the Caribbean: On Stranger Tides** (Average Depth Budget: 0.94%)

    - Second Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2011)
    - First Place in Scale Mismatch among Natively Captured Movies (released in 2011)

- First Place in Rotation Mismatch among Natively Captured Movies (released in 2011)

13. **Into the Deep** (Average Depth Budget: 3.74%)

    - **Second Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**
    - Third Place in Scale Mismatch among Natively Captured Movies (released in 2010 and earlier)
    - Third Place in Rotation Mismatch among Natively Captured Movies (released in 2010 and earlier)

14. **The Great Gatsby** (Average Depth Budget: 1.20%)

    - Third Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - First Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

15. **The Three Musketeers** (Average Depth Budget: 0.77%)

    - Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Scale Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

16. **47 Ronin** (Average Depth Budget: 0.79%)

    - Second Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Third Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Third Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)

17. **Underworld: Awakening** (Average Depth Budget: 0.69%)

    - Second Place in Color Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
    - Third Place in Vertical Parallax among Natively Captured Movies ($300<budget<$1000K/min)
    - Third Place in Rotation Mismatch among Natively Captured Movies ($300<budget<$1000K/min)

18. **Spy Kids 3-D: Game Over** (Average Depth Budget: 2.40%)

    - **Second Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**

- Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2010 and earlier)

19. **Oz the Great and Powerful** (Average Depth Budget: 1.05%)

    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2013 and early 2014)
    - Second Place in Scale Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Second Place in Rotation Mismatch among Natively Captured Movies (released in 2013 and early 2014)

20. **Hugo** (Average Depth Budget: 1.57%)

    - Third Place in Color Mismatch among Natively Captured Movies (released in 2011)
    - Third Place in Vertical Parallax among Natively Captured Movies (released in 2011)

21. **Jack the Giant Slayer** (Average Depth Budget: 0.84%)

    - Third Place in Sharpness Mismatch among Natively Captured Movies (released in 2013 and early 2014)
    - Third Place in Sharpness Mismatch among Natively Captured Movies (budget>$1000K/min)

22. **Dial M for Murder** (Average Depth Budget: 2.02%)

    - **First Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
    - **First Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**

23. **Avatar** (Average Depth Budget: 1.69%)

    - **Third Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**
    - First Place in Vertical Parallax among Natively Captured Movies (released in 2010 and earlier)

24. **Space Station 3D** (Average Depth Budget: 2.06%)

    - **Second Place in Vertical Parallax/Release Date Trade-off among Natively Captured Movies**
    - **Second Place in Rotation Mismatch/Release Date Trade-off among Natively Captured Movies**

25. **A Very Harold & Kumar 3D Christmas** (Average Depth Budget: 0.89%)

    - Second Place in Vertical Parallax among Natively Captured Movies (released in 2011)

- Third Place in Rotation Mismatch among Natively Captured Movies (released in 2011)

26. **Battle of the Year** (Average Depth Budget: 0.91%)
    - Third Place in Color Mismatch among Natively Captured Movies (released in 2013 and early 2014)
27. **Ghosts of the Abyss** (Average Depth Budget: 2.56%)
    - **Third Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
28. **Cirque du Soleil: Journey of Man** (Average Depth Budget: 1.50%)
    - **Third Place in Scale Mismatch/Release Date Trade-off among Natively Captured Movies**
29. **Step Up Revolution** (Average Depth Budget: 1.15%)
    - Third Place in Scale Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
30. **Sea Rex 3D: Journey to a Prehistoric World** (Average Depth Budget: 1.24%)
    - Second Place in Sharpness Mismatch among Natively Captured Movies (released in 2011)
31. **Galapagos: The Enchanted Voyage** (Average Depth Budget: 2.57%)
    - **First Place in Sharpness Mismatch/Release Date Trade-off among Natively Captured Movies**
32. **Creature from the Black Lagoon** (Average Depth Budget: 3.18%)
    - **Second Place in Color Mismatch/Release Date Trade-off among Natively Captured Movies**
33. **Resident Evil: Retribution** (Average Depth Budget: 0.87%)
    - Second Place in Sharpness Mismatch among Natively Captured Movies ($300<budget<$1000K/min)
34. **My Bloody Valentine** (Average Depth Budget: 1.69%)
    - Third Place in Color Mismatch among Natively Captured Movies (released in 2010 and earlier)

Chapter 5

Unsolved Problems and Possible Next Steps

5.1 Universal Fatigue Metric

Among our main research areas is development of a general metric for predicting visual fatigue caused by watching S3D video. Some may argue that development of a universal fatigue metric is impossible owing to high and unpredictable variance in human reaction to S3D artifacts and to creative choices throughout the production. This variance does occur, but it doesn't preclude creation of a universal metric. For example, one possibility is to predict the fraction of individuals who experience noticeable discomfort during or after watching a full-length S3D movie. This metric is reasonable and could be estimated directly by querying people in theaters. But predicting its value on the basis of the S3D content is a complicated task.

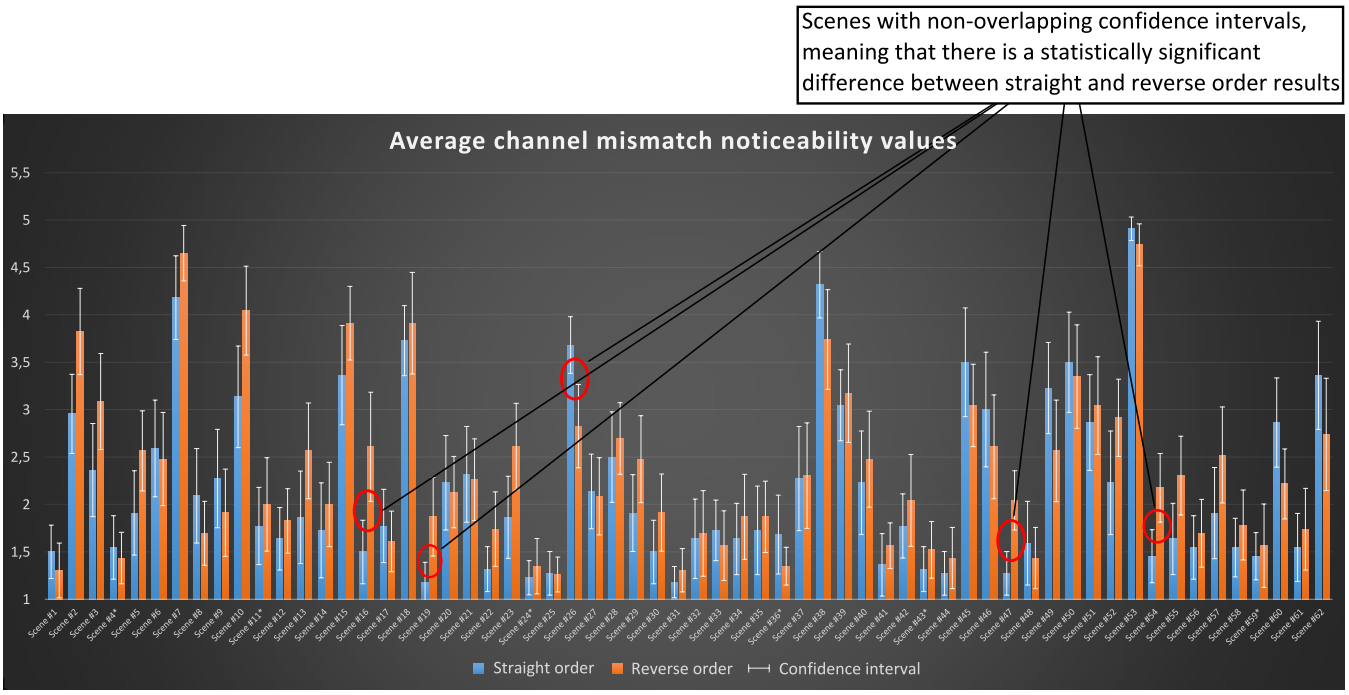


Figure 5.1: The illustration of difference between subjective evaluation results obtained while showing test scenes in straight and reverse order. Courtesy of CS MSU Graphics & Media Lab

Development of a universal fatigue metric involves a range of challenges associated with conducting proper subjective evaluations. For instance, while performing a subjective evaluation of channel-mismatch noticeability (our results appear in the Channel Mismatch section), we faced the problem of significantly different subjective marks when the test scenes were shown in reverse order compared with forward (each subject watched the sequence only once, either in forward or reverse order). Figure 5.1 illustrates this effect.The deviation clearly goes beyond statistical error and results from underlying dependencies that

we neglected to take into account. Though we obtained our results by simple averaging of forward and backward passes, more-involved techniques may be beneficial. Other problems that further complicate proper fatigue estimation include the following:

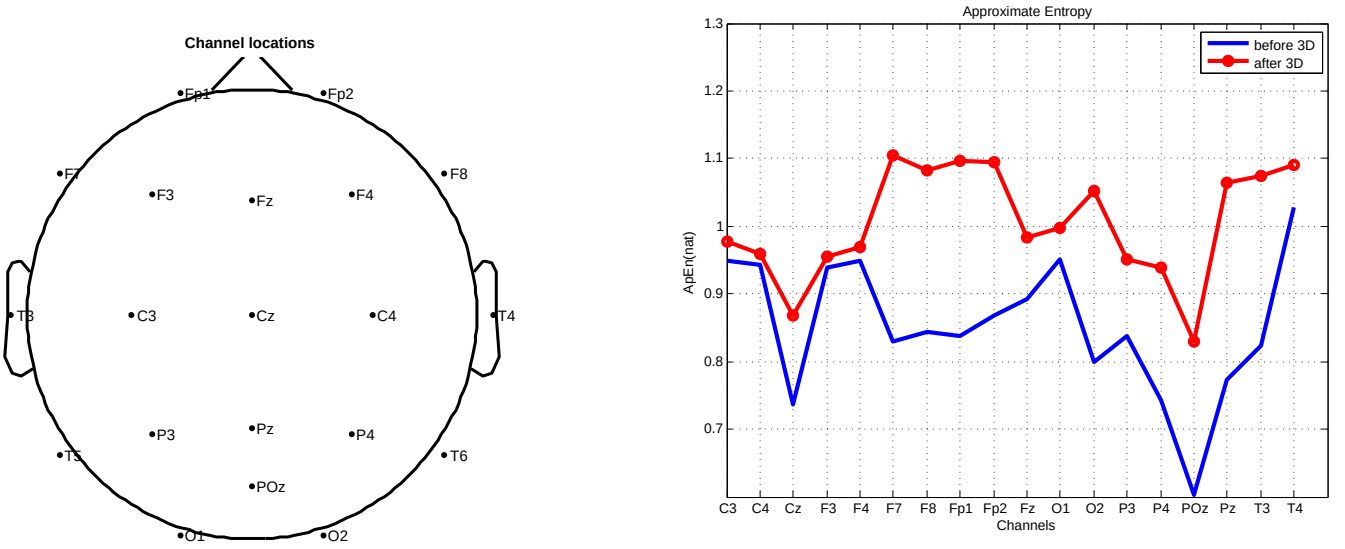
- The capabilities of binocular vision can vary dramatically among test subjects, so additional effort is necessary to correctly represent all groups of people.
- We must explicitly consider the problems of stereoscopic-display technologies (crosstalk, low brightness, etc.) that can also lead to noticeable discomfort.
- Because the effect of many minor artifacts (as opposed to several major ones that are immediately noticeable) can accumulate and produce noticeable fatigue only after long viewing sessions, capturing this kind of fatigue requires lengthy experiments.

Once the procedure for subjective evaluation of fatigue caused by S3D content is established, we will be able to develop a metric that predicts the results of these evaluations by analyzing S3D artifacts and other characteristic features of the content. We recognize, however, the many challenges and overall complexity of the task. Thus, we're open to collaboration in this research area. Our main interest is cooperation with subjective-evaluation specialists, particularly in the fields of fatigue estimation and binocular vision.

We're looking for scientific partnerships to develop a subjective-evaluation method

If you're interested in creating a universal fatigue metric for S3D, please contact us: 3dmovietest@graphics.cs.msu.ru

5.2 Objective Fatigue-Estimation and Improvement of Artifact Metrics



(a) Schematic illustration of channel locations

(b) The results of measurements before and after viewing an S3D video

Figure 5.2: An early result of applying EEG for evaluating fatigue caused by the low quality of S3D content. Courtesy of CS MSU Graphics & Media Lab

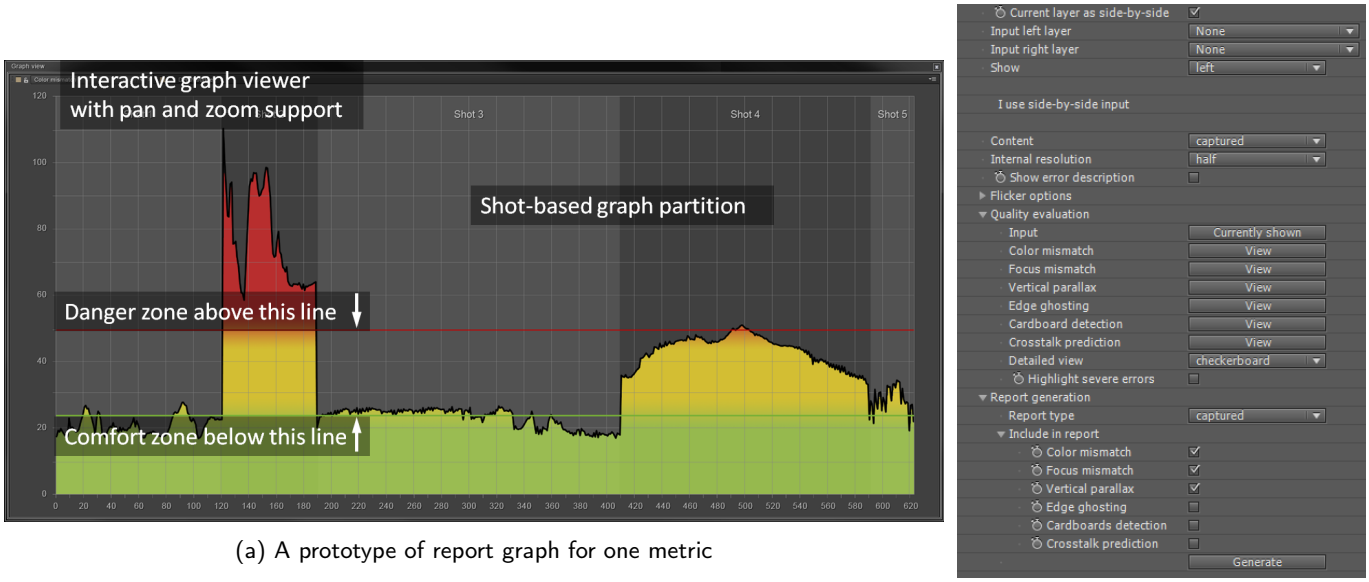
Another prominent research area is objective metrics for evaluating a test subject's mental state as an alternative to subjective tests. But state-of-the-art techniques for objective fatigue estimation often fail to properly capture viewer discomfort caused by watching low-quality S3D content. For example, we've tried several techniques that objectively estimate discomfort caused by S3D video with swapped channels, including estimation of critical flicker-fusion frequency (CFF). All of them exhibited practically no correlation with discomfort reported by the test subjects. One focus of our research is analysis of electroencephalography (EEG) results to objectively estimate visual fatigue and discomfort caused by S3D-content quality. Our first attempts in this area have shown promising results (Figure 5.2).

Objective fatigue evaluations, as well as the subjective tests we describe in the previous section, are crucial for improving all of our metrics and making them more perceptually oriented rather than purely technical. Ground-truth fatigue estimates will also enable us to rate artifacts on the basis of their contribution to overall viewer fatigue and discomfort. This area is therefore vital to further progress of our project, and as always, we're open to collaboration.

We are looking for scientific collaboration with specialists in fatigue analysis and binocular vision

If you are interested in objective evaluation of fatigue and discomfort caused by watching S3D movies, please contact us: 3dmovietest@graphics.cs.msu.ru

5.3 Developing a Tool for S3D-Video Quality Assessment



(a) A prototype of report graph for one metric

(b) User interface of an alpha version

Figure 5.3: An illustration of the proposed tool. Main features include automated report generation for arbitrary video sequence using a customizable set of quality metrics, highlighting the most severe errors, automatic generation of text descriptions for detected errors. Courtesy of YUVSoft Corp.

VQMT3D stands for "video quality measurement tool", so developing a tool remains a major goal. Such a product would enable automatic quality assurance for S3D content according to a wide range of technical parameters for both converted and natively captured S3D movies. It could also simplify or even eliminate daily review sessions by automatically detecting the main problems and subsequently generating to-do lists for contractors. Figure 5.3 shows an alpha version.

A main reason why the tool remains in an early development stage is the stagnation of the S3D market and subsequent lack of demand. Few potential customers are ready to pay for such a product, so we're looking for project partners.

We are looking for partnership in promoting S3D quality control tools and studios interested in using such tools

If you are interested in promotion and sales or if you are interested in using quality control tools in your work, please contact us: 3dmovietest@graphics.cs.msu.ru

5.4 Performance Comparison of S3D-Artifact-Correction Tools

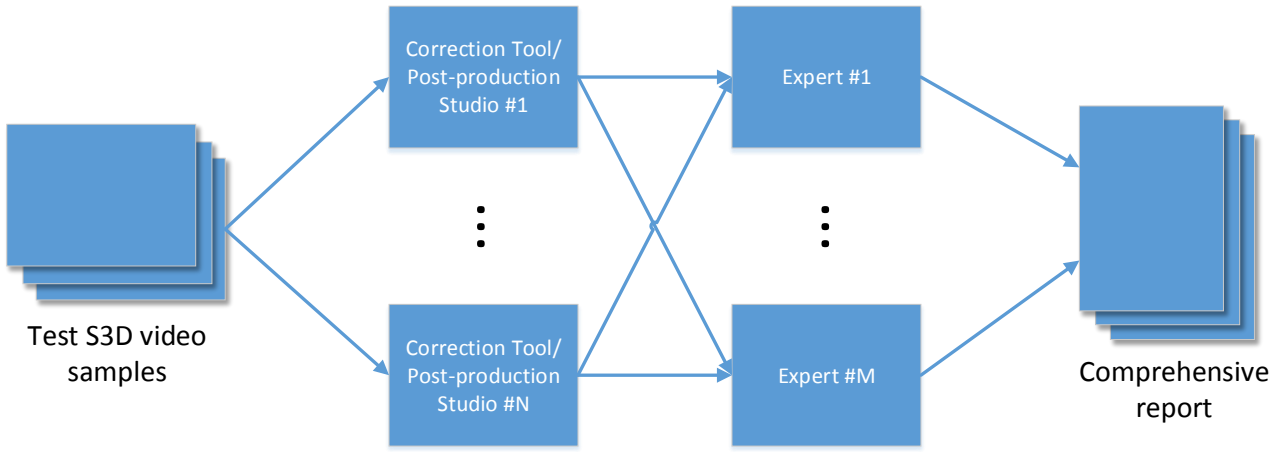


Figure 5.4: Schematic illustration of proposed workflow for comparing S3D artifact correction tools and/or post-production studios. Courtesy of CS MSU Graphics & Media Lab

Another interesting possibility is an extensive independent performance comparison of automatic correction tools on the basis of both objective criteria (our quality-metric results, correction speed, etc.) and subjective criteria (expert evaluation of correction quality, usability, etc.). Alternatively, a comparison of volunteer postproduction studios could examine both the speed and quality of their work. In this scenario, studios would receive test S3D-video samples of varying correction difficulty, and independent experts would blindly assess the results. The analysis could employ some objective metrics as well. Figure 5.4 illustrates the overall scheme.

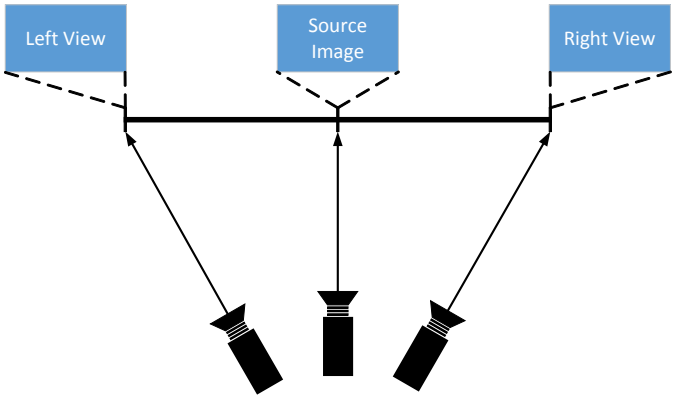
Our lab has vast experience in conducting similar comparisons for video-compression quality.Annual MSU video-codec comparisons (`https://videoprocessing.ml/codecs/`) are widely known throughout the community and have proven beneficial to the industry. We've published 19 reports since 2003, totaling over 600,000 downloads. We believe introducing standards for S3D postproduction quality can also be helpful.

This project is in an early concept stage, so we welcome feedback and suggestions. We're seeking experts and postproduction studios willing to participate in the comparison. In addition, we're looking for independent funding (i.e., from partners with no conflict of interest) to support the project.

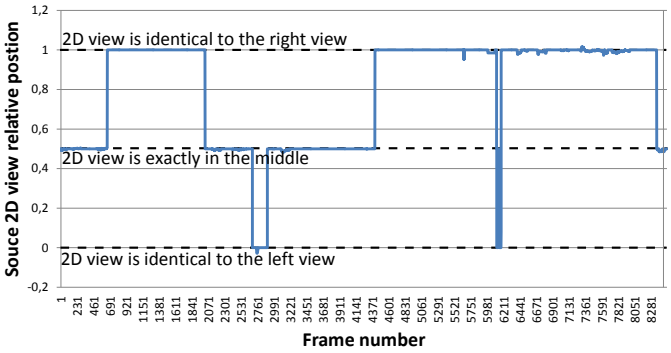
We are looking for experts and studios that are willing to participate in the comparison, as well as independent funding for the project

If you are interested, please contact us: 3dmovietest@graphics.cs.msu.ru

5.5 Improving Analysis of 2D-to-3D Conversion



(a) Schematic illustration of a common case where source image is located exactly in the middle between the left and right views



(b) An example per-frame chart depicting relative 2D source image position

Figure 5.5: Source 2D image potentially can be located anywhere between the views of the resulting S3D video. The choice is usually dictated by specifics of the background texture, while the goal is to minimize the work on occlusion filling. Courtesy of CS MSU Graphics & Media Lab

Besides improving the edge-sharpness-mismatch metric [3,5], which remains unable to quantitatively assess 2D-to-3D conversion quality, we have two main research directions: more-thorough and more-accurate comparison of 2D and 3D versions of converted movies, and assessment of depth-map quality by detecting depth/motion inconsistencies. The main goal of this project is to find reasonable ways to quantitatively assess 2D-to-3D conversion quality. Converted movies today have a major advantage in nearly all of our comparisons because we still lack quantitative metrics for analyzing 2D-to-3D conversion issues.

Planned improvements to the 2D- and 3D-version comparison include the following:

- More-advanced quantitative analysis of geometric inconsistencies between 2D and 3D versions, such as global scaling transforms as well as local object scaling. These kinds of approaches are commonly used to simplify the conversion process. For instance, local scaling of foreground objects can reduce or eliminate the need to explicitly fill occlusions.
- Explicit estimation of source-frame position relative to left and right views in the resulting S3D video. The source image often resides in the exact middle between the left and right views, but many other configurations are possible (see Figure 5.5).

More-advanced analysis of depth-map quality would allow us to more robustly detect and assess the cardboard effect. It would also let us detect regions that employed a rough or inaccurate depth map, leading to noticeable artifacts—for example, regions where depth-map edges fail to align with the real object edges..

We are looking for scientific collaboration on developing 2D-3D conversion technical quality metrics

If you are interested in objective quality evaluation of 2D-3D conversion, please contact us: 3dmovietest@graphics.cs.msu.ru

5.6 VR180 Analysis

VR180 is a new virtual-reality (VR) format that improves perception of VR video. Google announced details in April 2018. Comparison of the new format with existing 360 video reveals the following differences:

- *Economy*. The new format focuses only on the front 180 degrees, because interesting events usually happen on that side of the video. A 360 video conveys not only the main image subject in front, but also the minor image in the back.
- *Stereoscopy*. VR180 is a stereoscopic format, potentially improving the presence effect relative to 360 video.
- *Low cost*. Even now, after the format's release, some VR180 cameras are lower in price than, for example, a stereo rig. Many manufacturers (such as Lenovo, LucidCam and Yi) have already released VR180 cameras.
- *No stitching*.This benefit is due to the architectural features of VR180 devices (they only use one fish-eye camera per view).

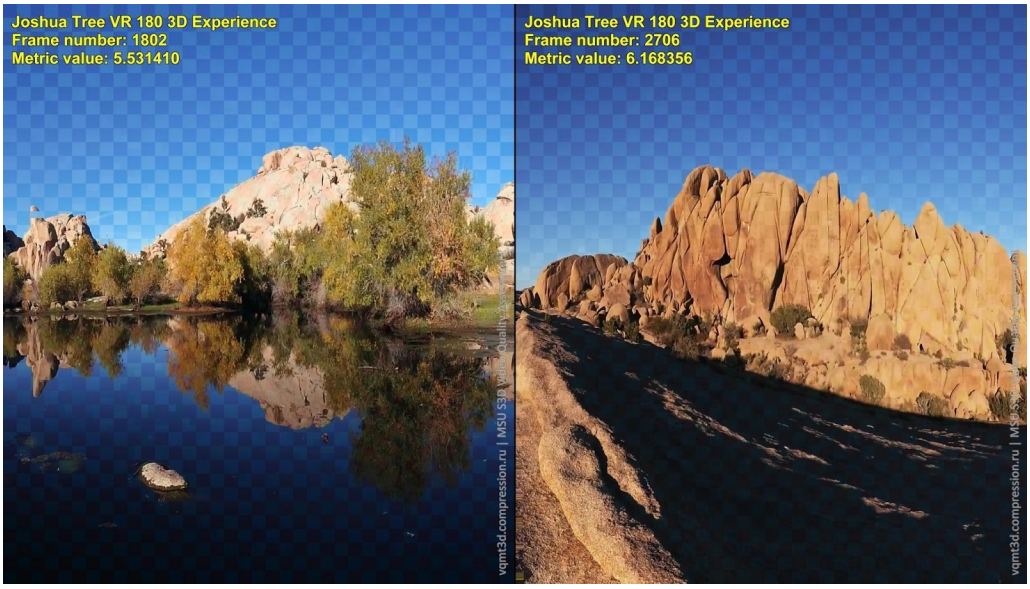
Note, however, that VR180 still has disadvantages:

- No VR180-postprocessing software is available.
- Inexpensive cameras capture poor stereoscopy, causing viewer discomfort.

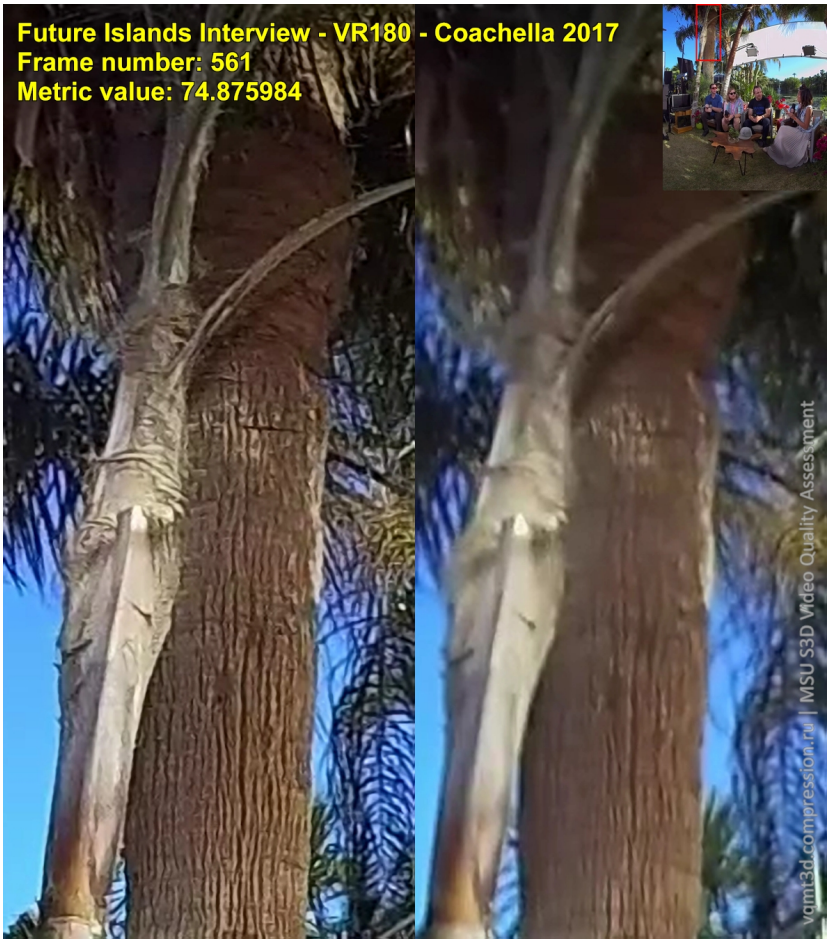
Even a basic check of VR180 content has shown that its quality is similar to that of conventional stereoscopic movies from around the middle of the last century. Below are examples of artifacts we discovered in VR180 video.

Color distortion

The most convenient way to visualize this artifact is to think of a chessboard where motion compensation brings the right view to the left, then blocks are selected from the left and reduced right views in a staggered manner.



The differences in sharpness



These and many other VR180 artifacts can cause viewer discomfort and, as a result, slow or even reverse any growth in the popularity of this format. We understand this challenge, and we're actively developing ways to assess VR180-video quality.

List of publications

[1] D. Vatolin, A. Voronov, D. Sumin, G. Rozhkova, V. Napadovsky, A. Borisov, and M. Arsaev, "VQMT3D Project Stereo-Film-Quality Analysis Report 1," 2013. [Online]. Available: http://compression.ru/video/vqmt3d/first-report

[2] D. Vatolin, A. Voronov, D. Sumin, G. Rozhkova, V. Napadovsky, A. Borisov, and M. Arsaev, "VQMT3D Project Stereo-Film-Quality Analysis Report 2," 2013. [Online]. Available: http://compression.ru/video/vqmt3d/second-report

[3] D. Vatolin, A. Voronov, D. Sumin, G. Rozhkova, V. Napadovsky, A. Bokov, V. Yanushkovsky, A. Belous, A. Shalpegin, A. Borisov, and M. Arsaev, "VQMT3D Project Stereo-Film-Quality Analysis Report 3," 2013. [Online]. Available: http://compression.ru/video/vqmt3d/report3

[4] D. Vatolin, A. Voronov, D. Sumin, G. Rozhkova, V. Napadovsky, A. Belous, V. Yanushkovsky, A. Borisov, and M. Arsaev, "VQMT3D Project Stereo-Film-Quality Analysis Report 4," 2013. [Online]. Available: http://compression.ru/video/vqmt3d/report4

[5] D. Vatolin, A. Voronov, D. Sumin, G. Rozhkova, V. Napadovsky, A. Bokov, V. Yanushkovsky, A. Belous, A. Shalpegin, A. Novikov, A. Borisov, and M. Arsaev, "VQMT3D Project Stereo-Film-Quality Analysis Report 5," 2014. [Online]. Available: http://compression.ru/video/vqmt3d/report5

[6] D. Vatolin, A. Bokov, O. Cahen, W. Sewell, R. Copeland, T. Villepoux, A. Fedorov, A. Belous, and V. Yanushkovsky, "VQMT3D Project Stereo-Film-Quality Analysis Report 6," 2014. [Online]. Available: http://compression.ru/video/vqmt3d/report6

[7] D. Vatolin, A. Bokov, O. Cahen, W. Sewell, R. Copeland, T. Villepoux, A. Fedorov, A. Belous, and V. Yanushkovsky, "VQMT3D Project Stereo-Film-Quality Analysis Report 7," 2014. [Online]. Available: http://compression.ru/video/vqmt3d/report7

[8] D. Vatolin, A. Bokov, A. Shalpegin, S. Lavrushkin, V. Yanushkovsky, and A. Fedorov, "VQMT3D Project Stereo-Film-Quality Analysis Report 8," 2015. [Online]. Available: http://compression.ru/video/vqmt3d/report8

[9] A. Voronov, D. Vatolin, D. Sumin, V. Napadovsky, and A. Borisov, "Towards automatic stereo-video quality assessment and detection of color and sharpness mismatch," in *International Conference on 3D Imaging (IC3D)*, 2012, pp. 1–6.

[10] A. Voronov, A. Borisov, and D. Vatolin, "System for automatic detection of distorted scenes in stereo video," in *Proceedings of the Sixth International Workshop on Video Processing and Quality Metrics (VPQM)*, 2012.

[11] D. Akimov, A. Shestov, A. Voronov, and D. Vatolin, "Automatic left-right channel swap detection," in *International Conference on 3D Imaging (IC3D)*, 2012.

[12] A. Voronov, D. Vatolin, D. Sumin, V. Napadovsky, and A. Borisov, "Methodology for stereoscopic

motion-picture quality assessment," in *Stereoscopic Displays and Applications XXIV, Proceedings of SPIE 8648*, 2013, pp. 864 810–864 810–14.

[13] A. Bokov, D. Vatolin, A. Zachesov, A. Belous, and M. Erofeev, "Automatic detection of artifacts in converted S3D video," in *Stereoscopic Displays and Applications XXV, Proceedings of SPIE 9011*, 2014, pp. 901 112–901 112–14.

[14] A. Ploshkin and D. Vatolin, "Accurate method of temporal-shift estimation for 3d video," in *2018 - 3DTV-Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2018, pp. 1–4.

[15] S. Lavrushkin and D. Vatolin, "Channel-mismatch detection algorithm for stereoscopic video using convolutional neural network," in *2018 - 3DTV-Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2018, pp. 1–4.

[16] A. Khatiullin, M. Erofeev, and D. Vatolin, "Fast occlusion filling method for multiview video generation," in *2018 - 3DTV-Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2018, pp. 1–4.

[17] S. Lavrushkin, V. Lyudvichenko, and D. Vatolin, "Local method of color-difference correction between stereoscopic-video views," in *2018 - 3DTV-Conference: The True Vision - Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2018, pp. 1–4.