Lag Can Kill – Measuring, Modeling and Mitigating the Effects of Latency on Game Players

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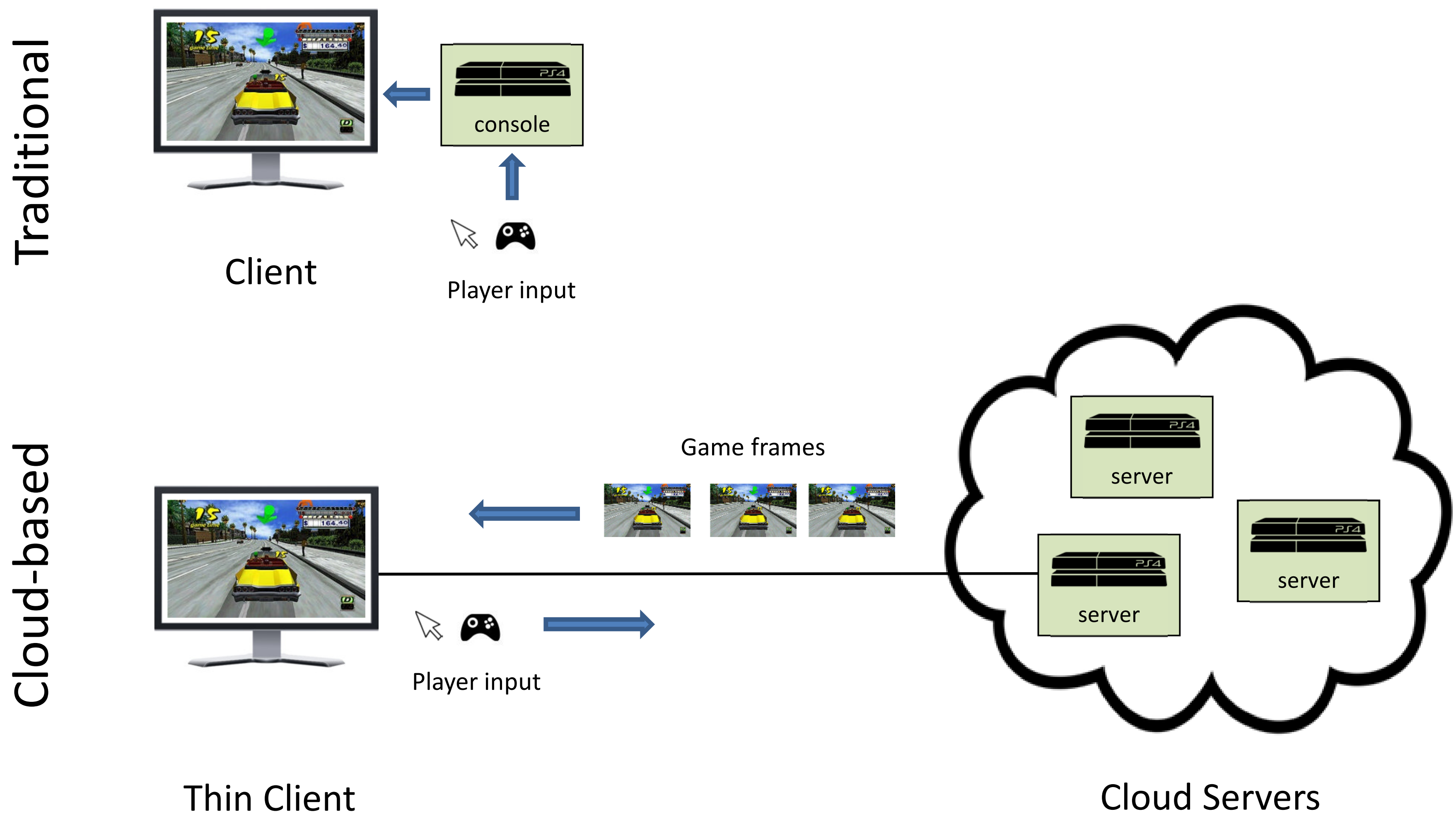
Introduction

- Real-time games sensitive to latency [Claypool, 2006]
  - Even tens of milliseconds of delay impacts player performance and quality of experience (QoE)
- Mitigate with *latency compensation* (algorithms that adjust game/system based on latency) [Bernier, 2001]
  - But *how* effective?
  - And *when* needed (what games/player actions)?
- Need research to better understand effects of latency on games
- More important now than ever with emergence of cloud-based games

Emergence of Cloud-based Games

- Sony PlayStation Now (‘14)
- Nvidia GeForce Now (‘15)
- Blade Shadow (‘17)
- Microsoft xCloud (‘19)
- Google Stadia (‘19)

What are Cloud-based Games?



Why Cloud-based Games?

- Complex games, simple hardware
  - $100 “thin” console vs. $300 PS4
  - 3D, HD games on limited devices (e.g., mobile phone)
- Elastic scalability – servers on demand
- Piracy prevention – server controls content
- Support fan streaming (e.g., Twitch)
- Click-to-play
  - *Shadow of War* [Warner Bros., 2017] → 97 GB
  - *League of Legends* [Riot Games, 2009] → Patched 200 times (22/year)

CLICK TO PLAY

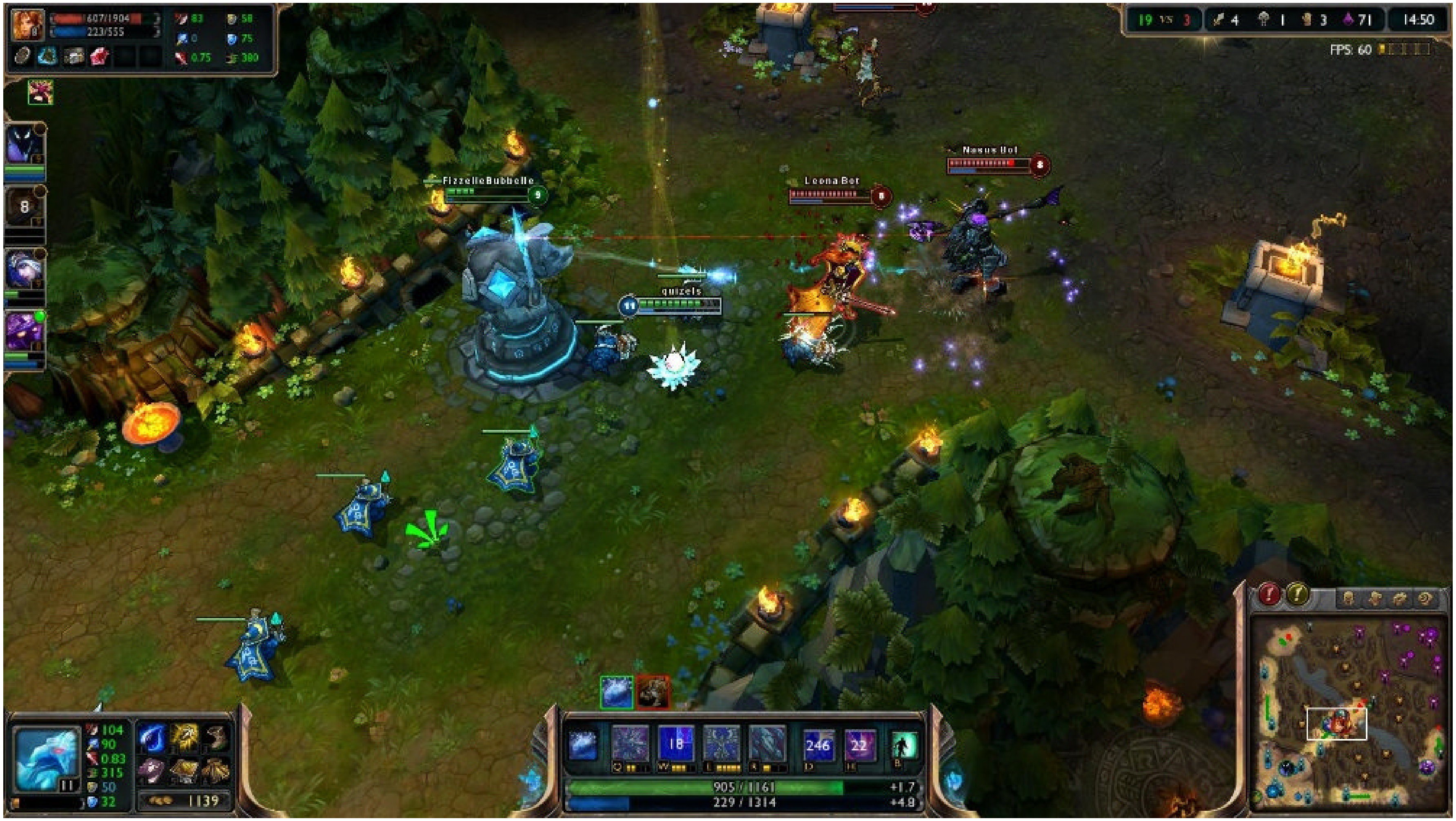
Outline

- Introduction (done)
- Challenges (next)
  - Capacity
  - Latency
- Latency and Games
- Latency Compensation
- Summary

Requirement – High Def Graphics

Uncharted 4 [Sony Entertainment, 2016]

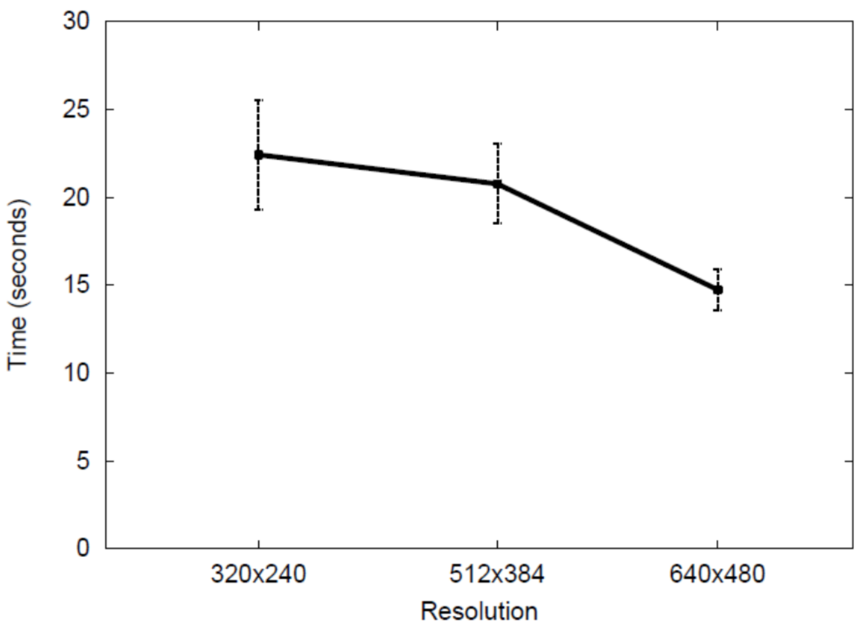
Requirement – High Def Graphics

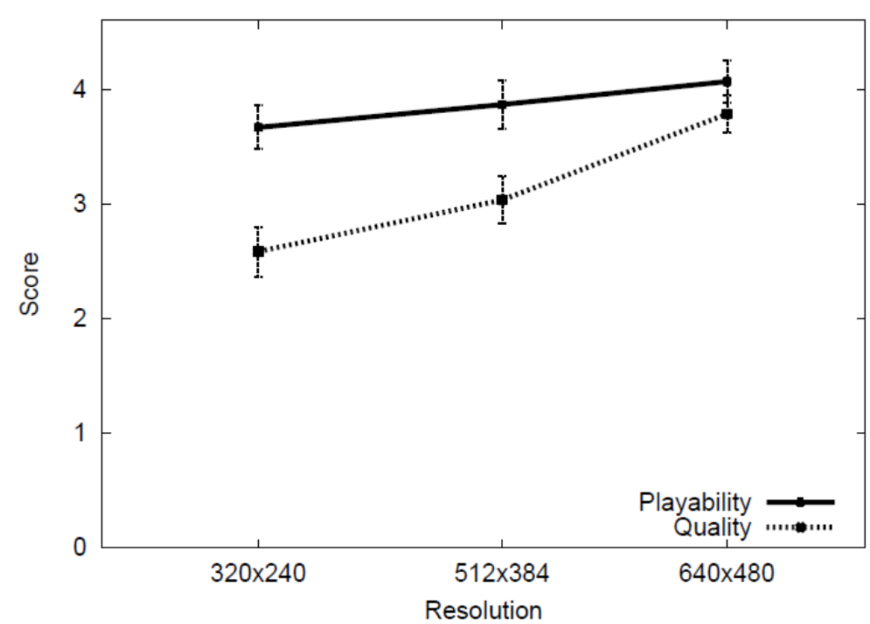


League of Legends

[Riot Games, 2009]

Requirement – High Def Graphics

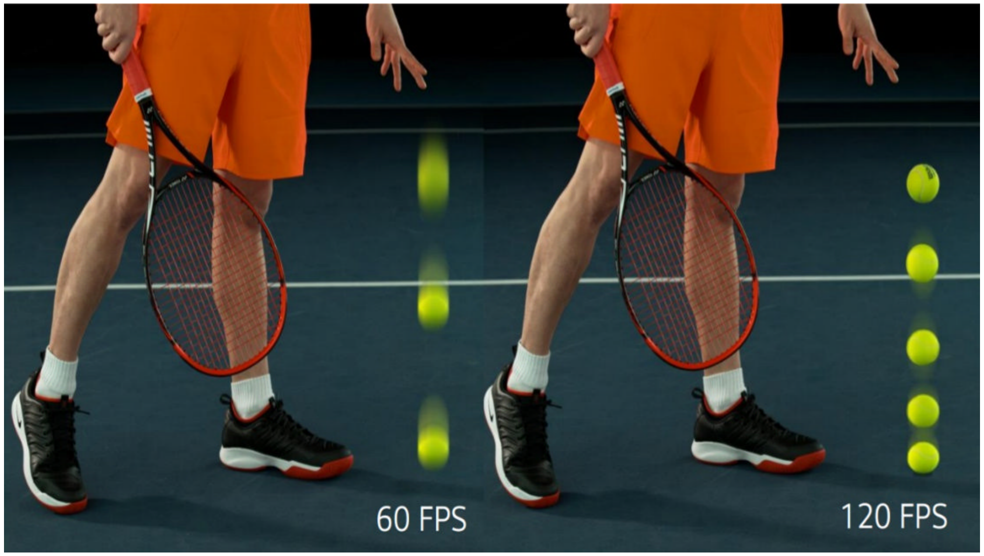




[Claypool and Claypool, 2007]

High definition graphics improve performance and Quality of Experience (QoE)

Requirement – High Frame Rates



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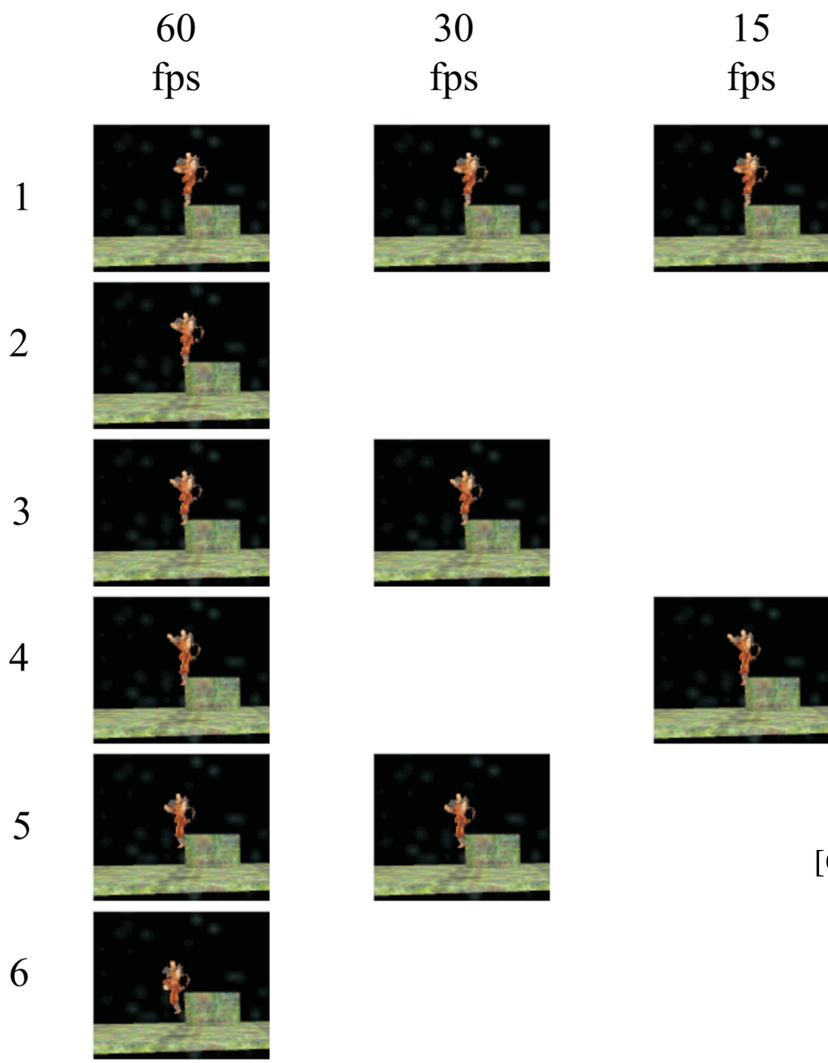
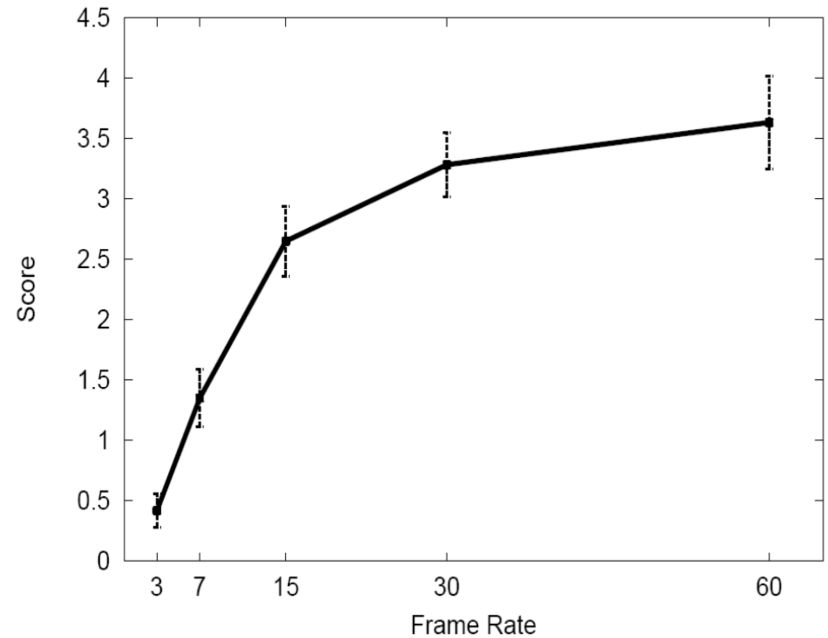
Requirement – High Frame Rates

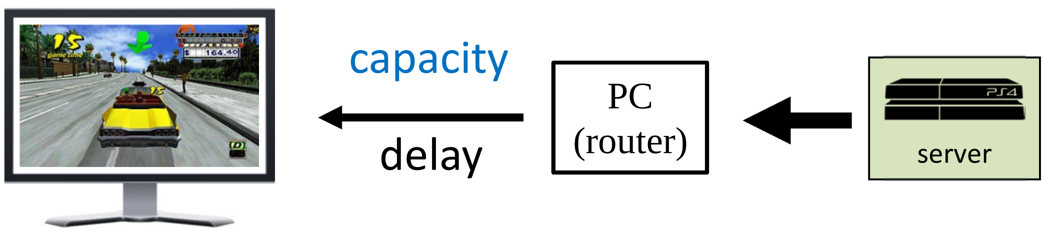


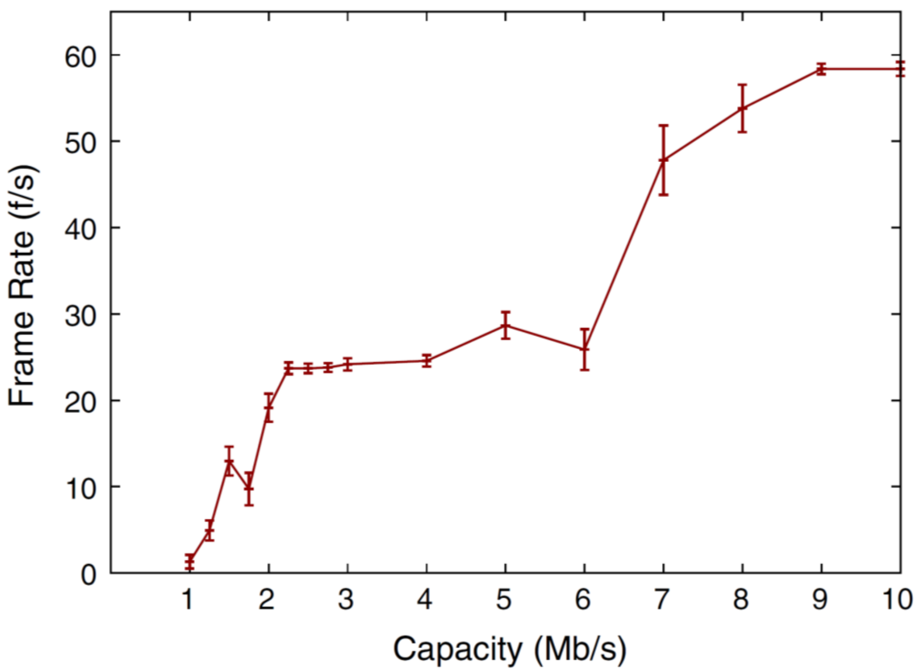


[Claypool et al, 2006]

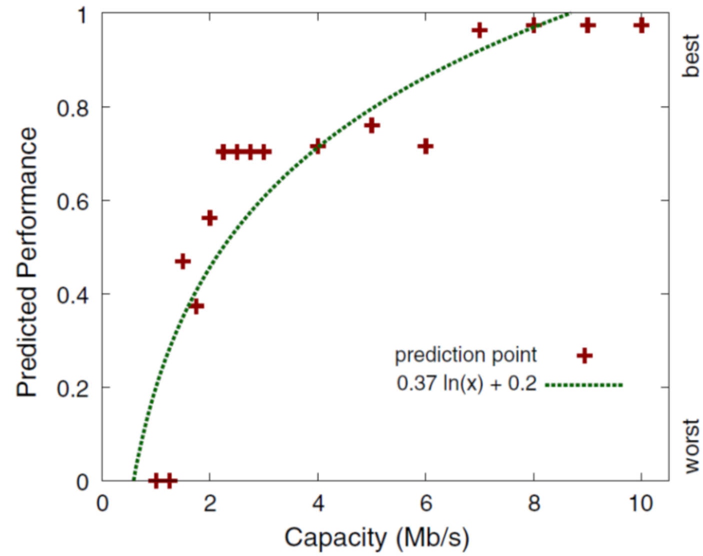
High frame rates improves performance and QoE

Challenge – Capacity





[Mark Claypool et al., 2014]

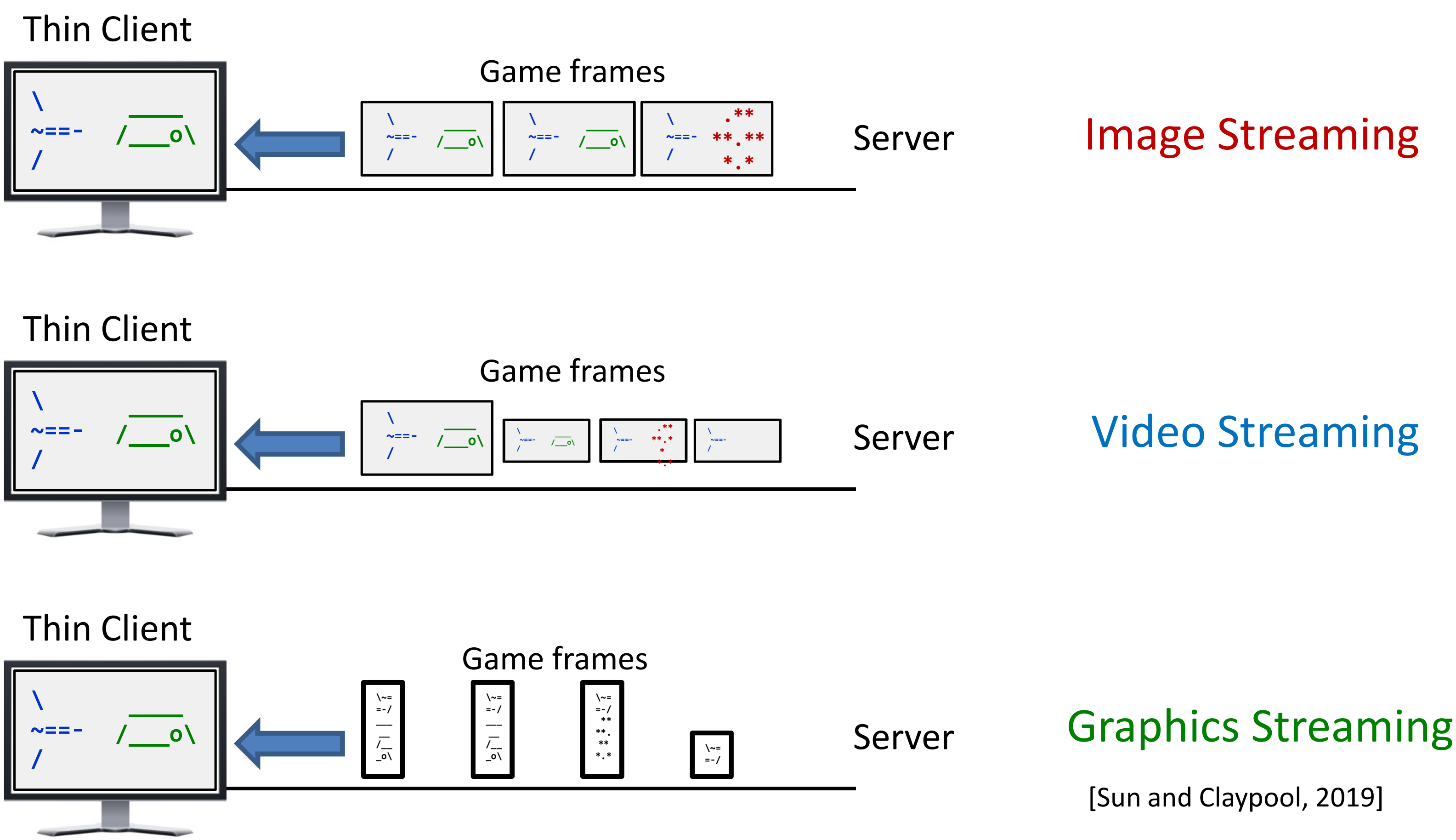


Application	Bitrate (kb/s)
Traditional game	67
Virtual environment	775
Live video	2,222
Thin Game	6,247

STADIA

- Minimum 10 Mb/s
- 4k, 60 f/s 35 Mb/s

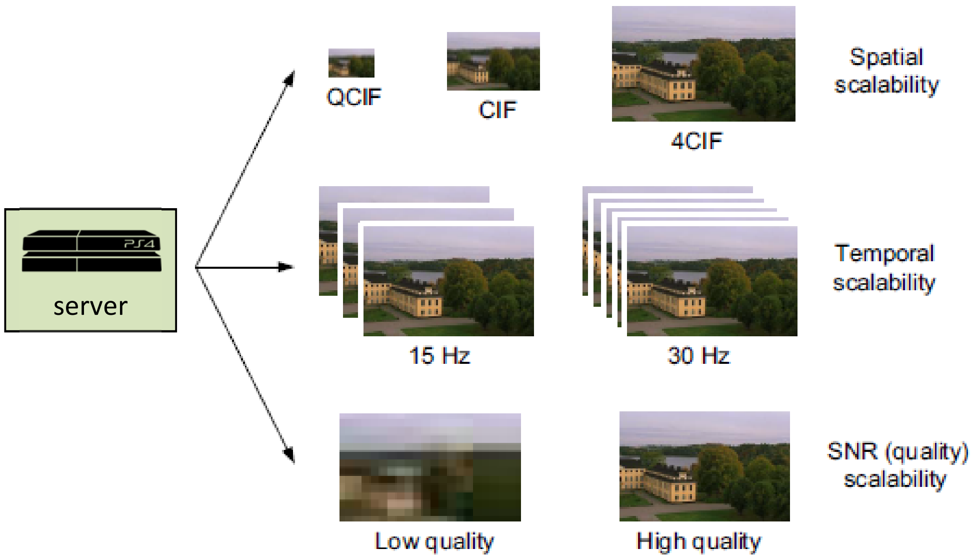
Approach – Graphics Streaming



[Sun and Claypool, 2019]

[DeWinter et al, 2006]

Approach – Media Scaling



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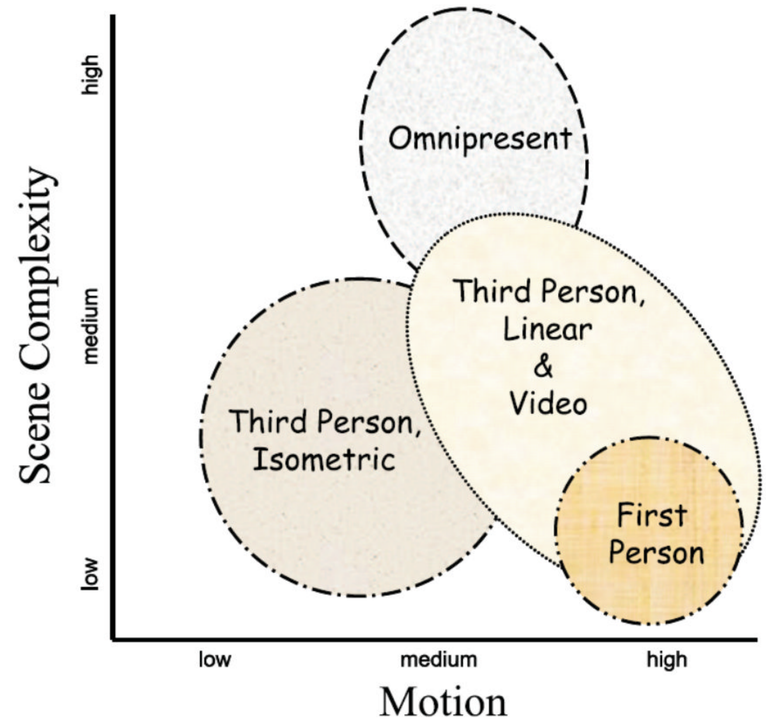

[Claypool, 2009]

- Knowing motion and scene complexity crucial to maximize quality [Wu et al., 2008]
  - High motion needs quality scaling
  - Low motion needs temporal scaling

Getting it "right" improves perceived quality by up to 50%

Outline

- Introduction (done)
- Challenges
  - Capacity (done)
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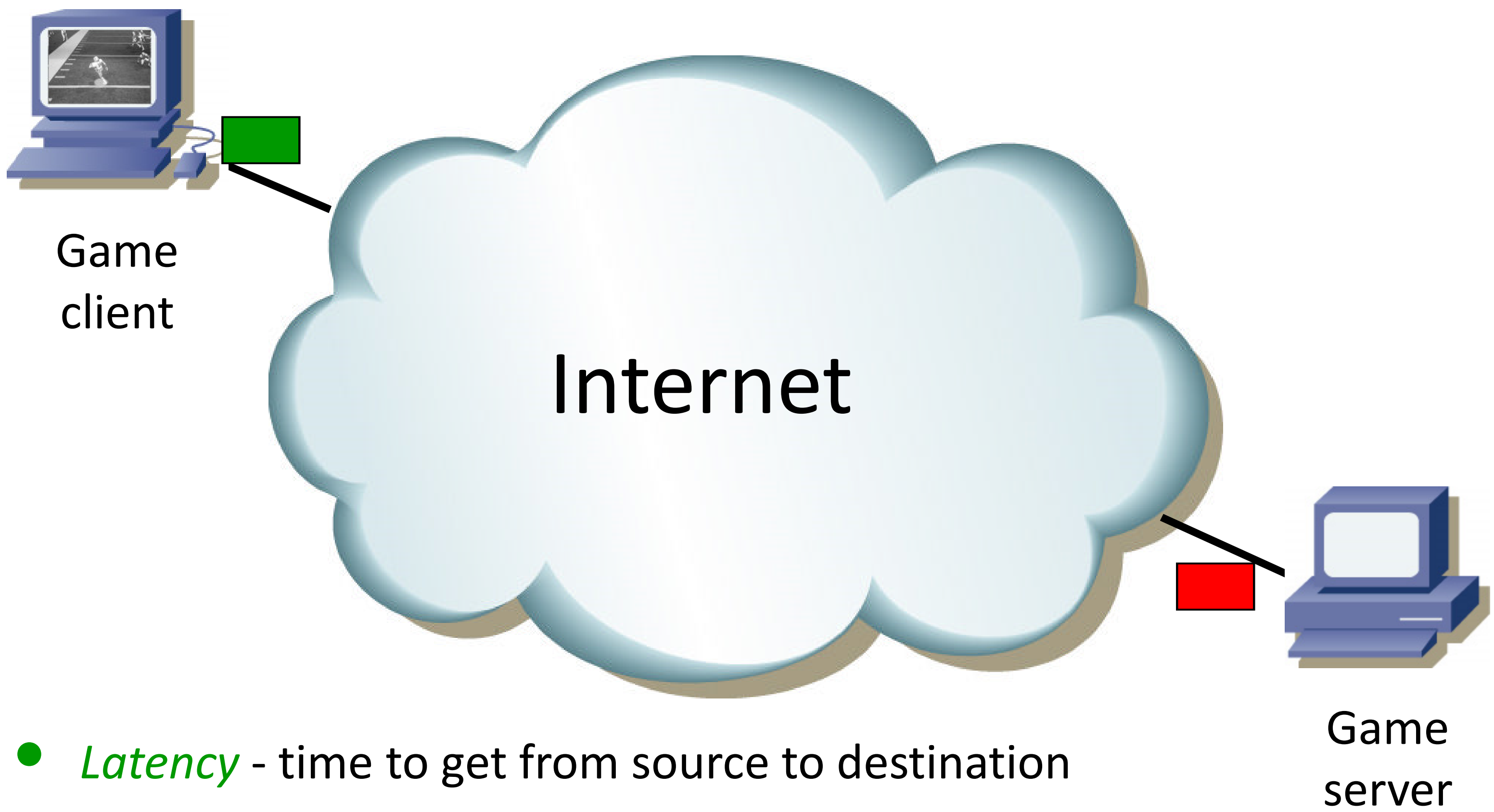
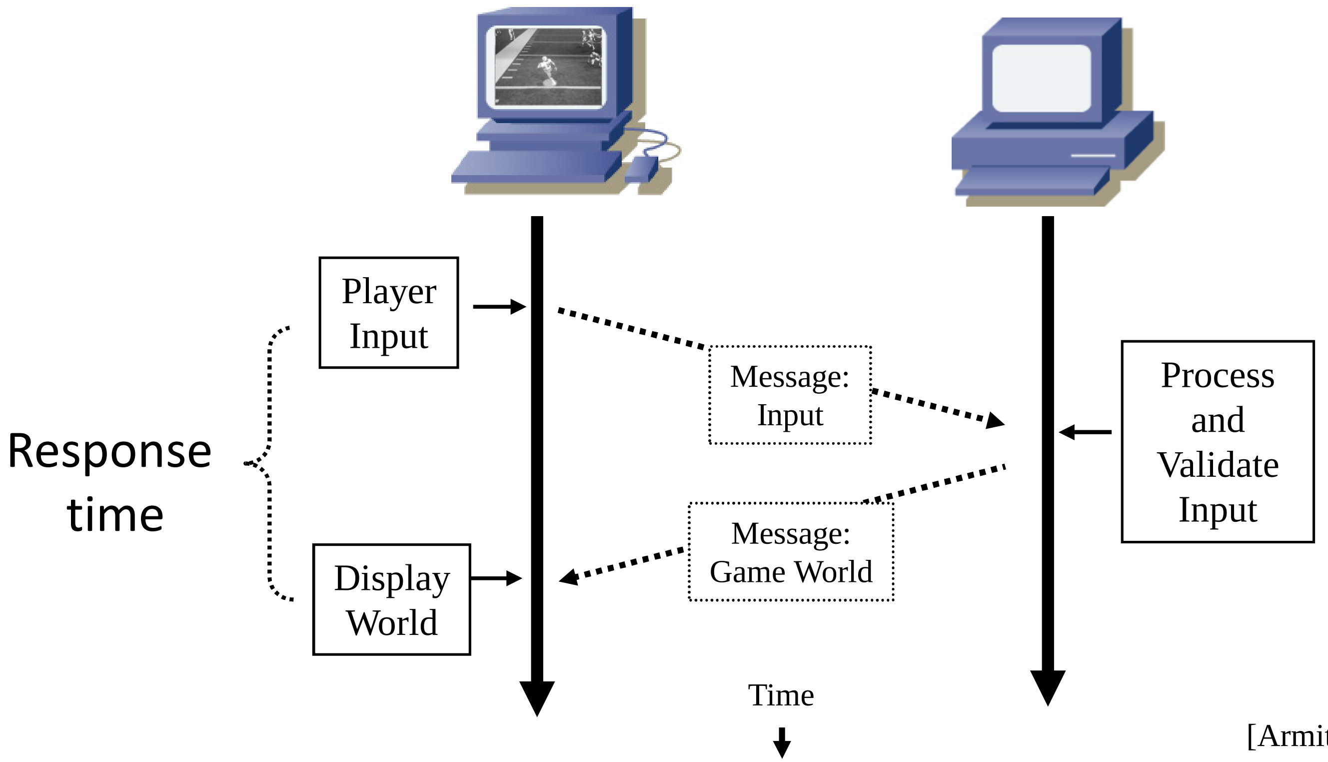
What is Latency for Network Games?



- *Latency* - time to get from source to destination
  - There and back (*round-trip time*)

Game traffic interactive, so can't be cached at edge
Additional capacity won't solve since limited by speed of light and host processing

Why Does Latency Matter?



[Armitage et al, 2006]

Degrades responsiveness

Outline

- Introduction (done)
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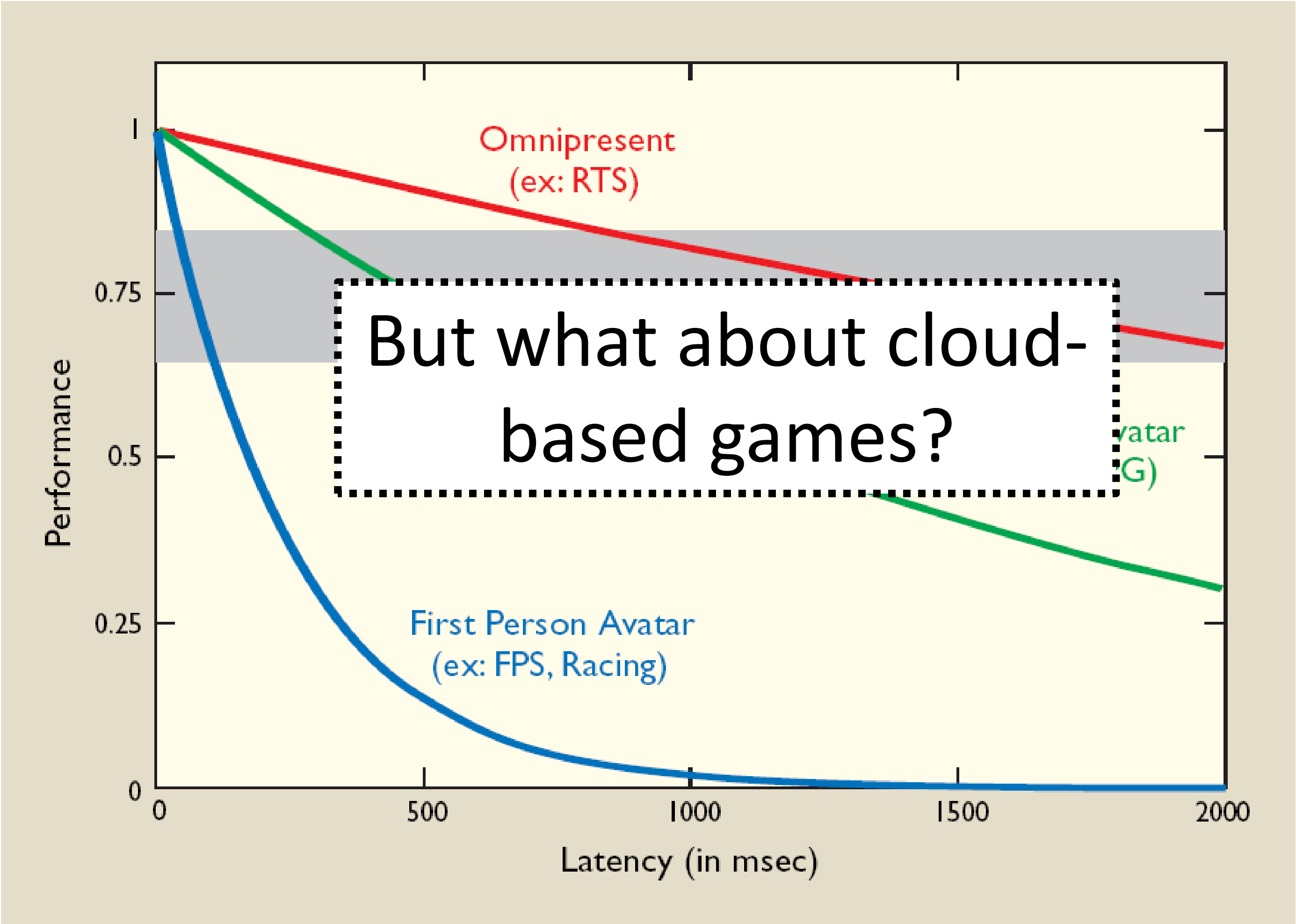
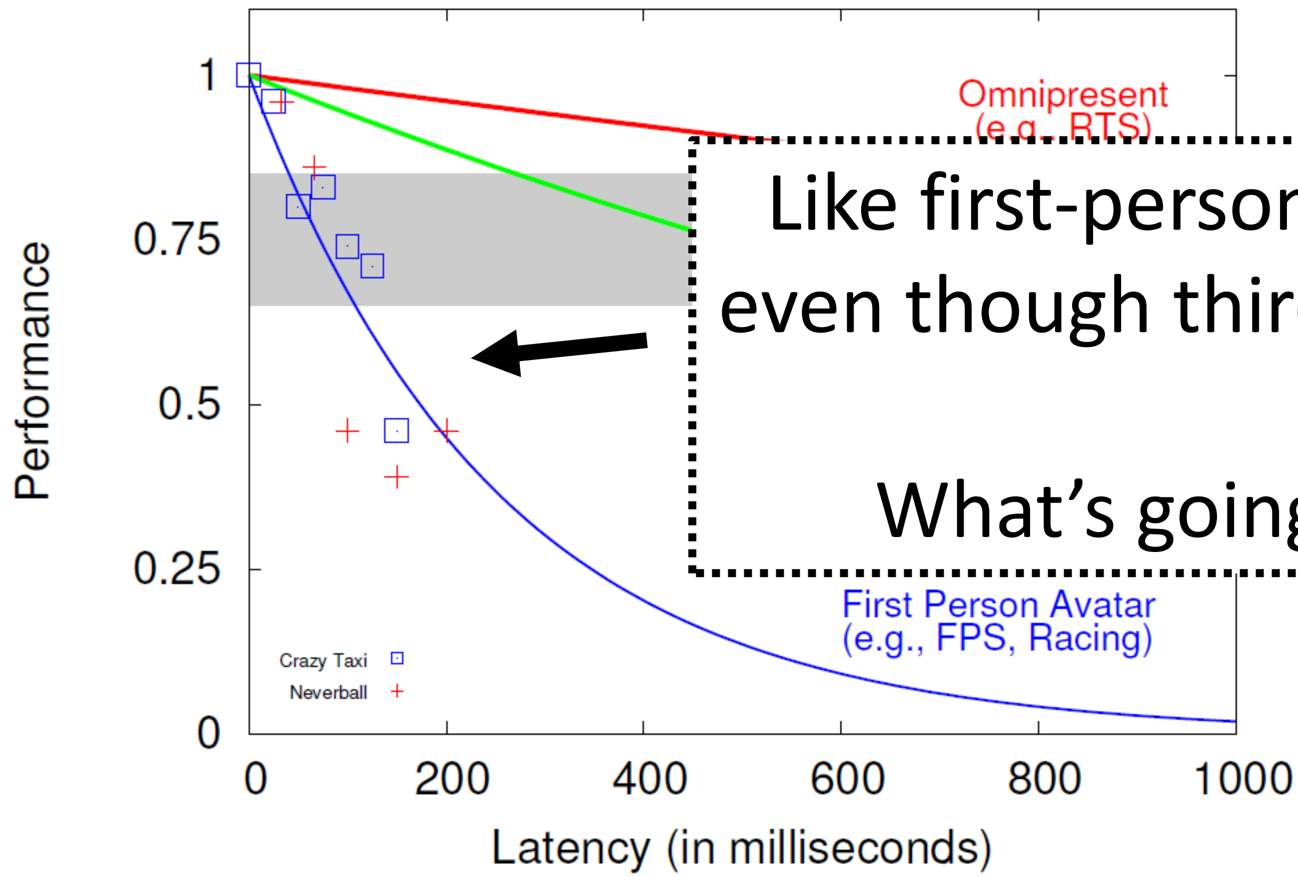
How Much Does Latency Matter?



[Claypool and Claypool, 2006]

Latency and Cloud-based Games



Like first-person games, even though third-person!

What's going on?

[Claypool and Finkel, 2014]

Research in Games and Delay

Effect of
delay on
games?

Research in Games and Delay

[Pantel, 2002]

[Armitage, 2003]

[Beigbeder, 2004]

[Nichols, 2004]

[Quax, 2004]

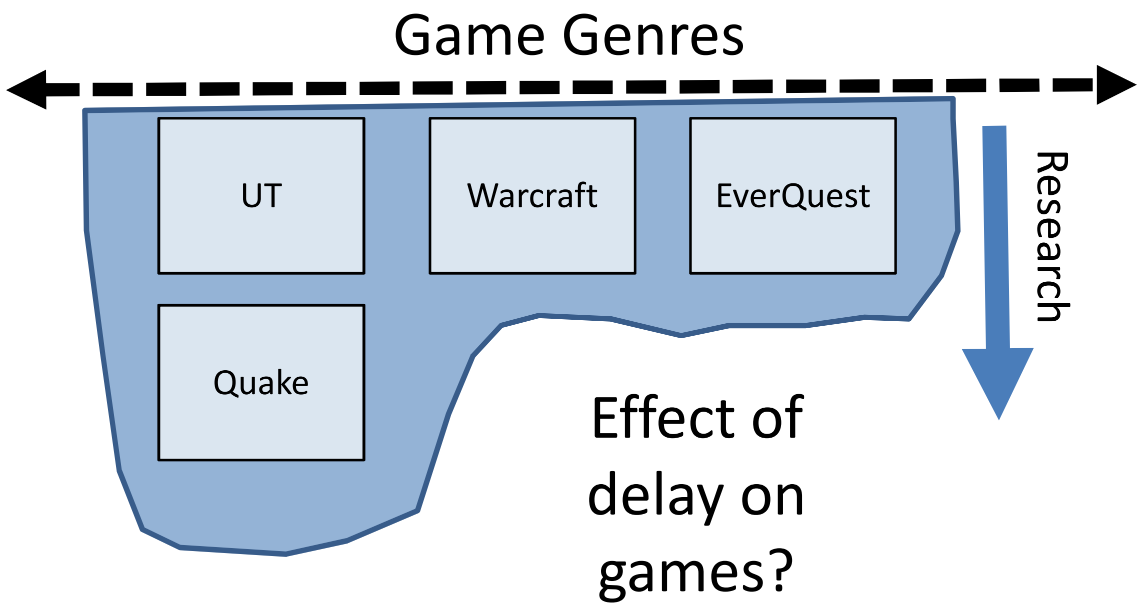
[Claypool, 2005]

[Amin, 2013]

[Chen, 2014]

[Fritsch, 2005]

[Ivkovic, 2017]



Research in Games and Delay

[Fitts, 1954]

[MacKenzie, 1992]

[Hajri, 2011]

[Raeen, 2011]

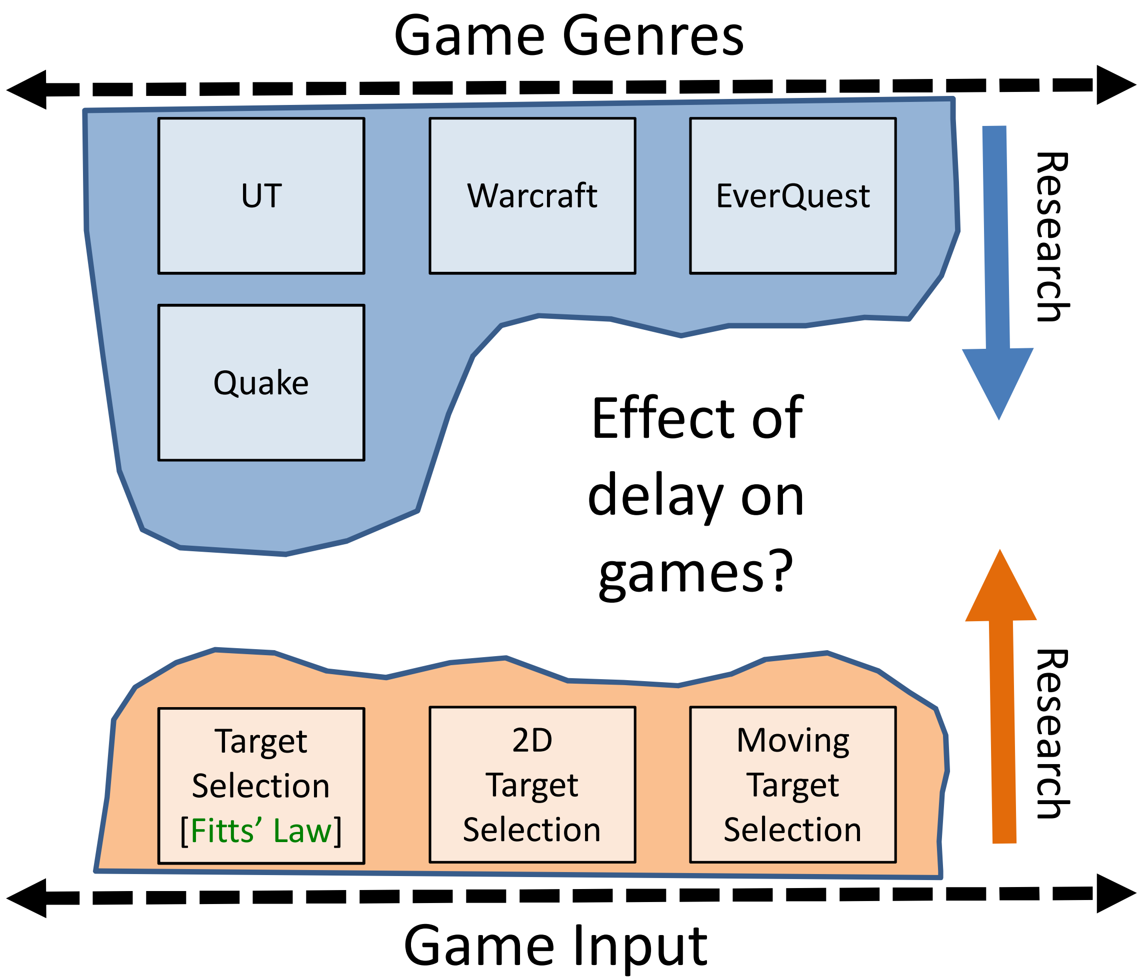
[Hoffman, 2012]

[Pavlovych, 2012]

[Raaen, 2015]

[Claypool, 2017]

[Long, 2018]



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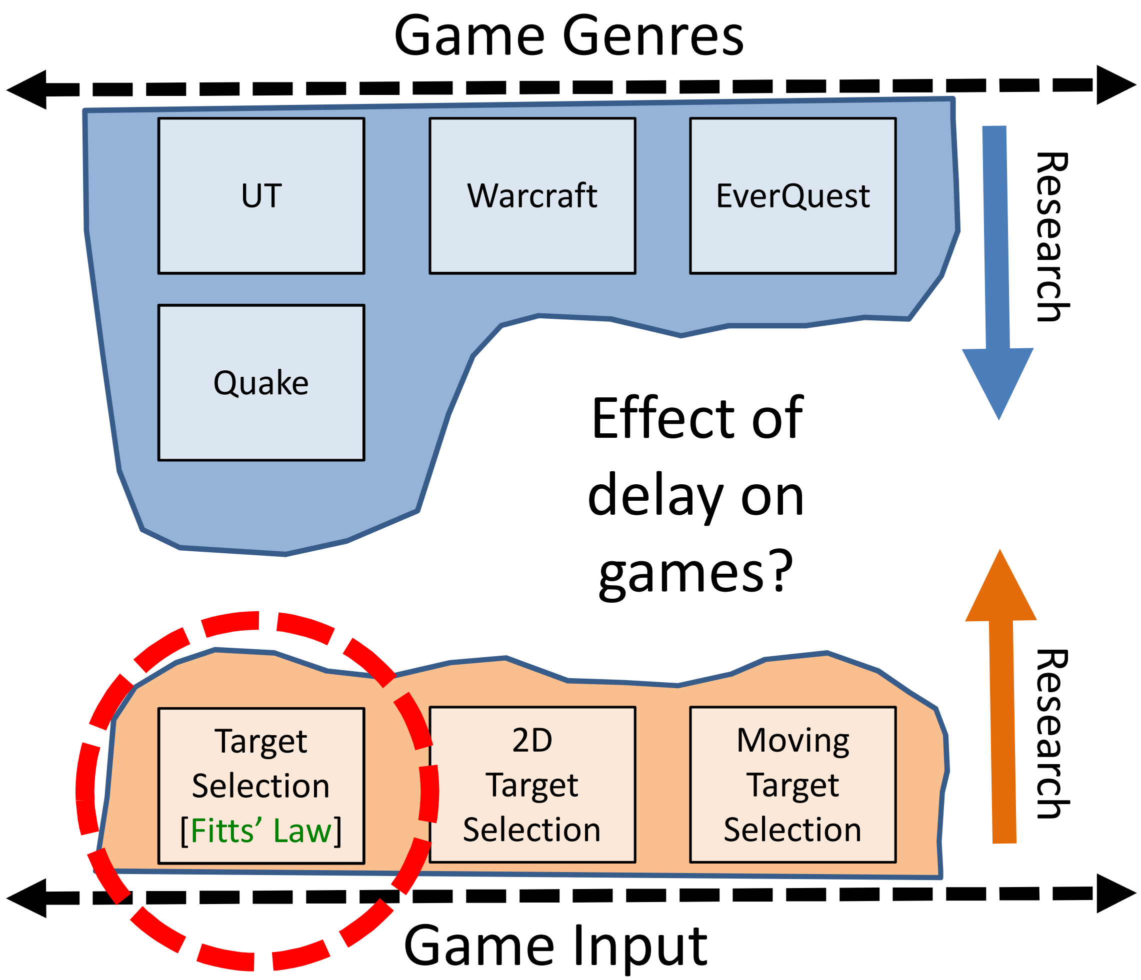
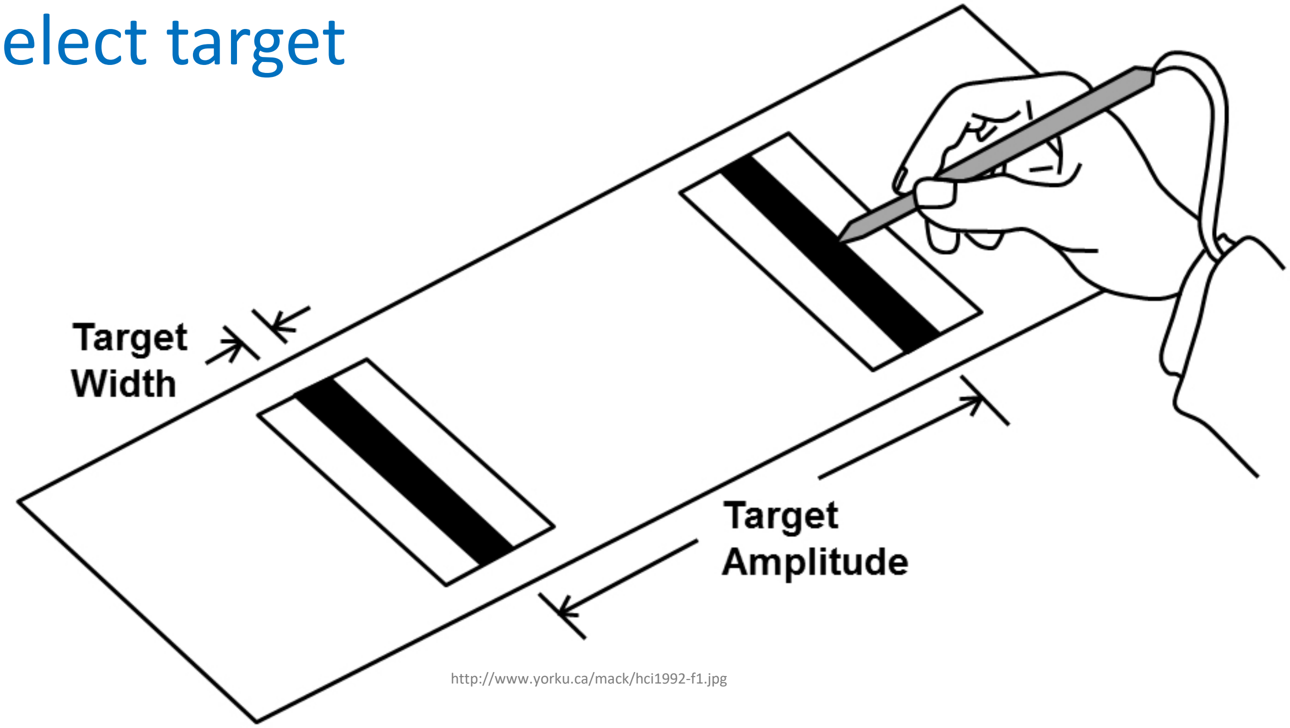


Fitts' Law

[Fitts, 1954]

Time to
select target

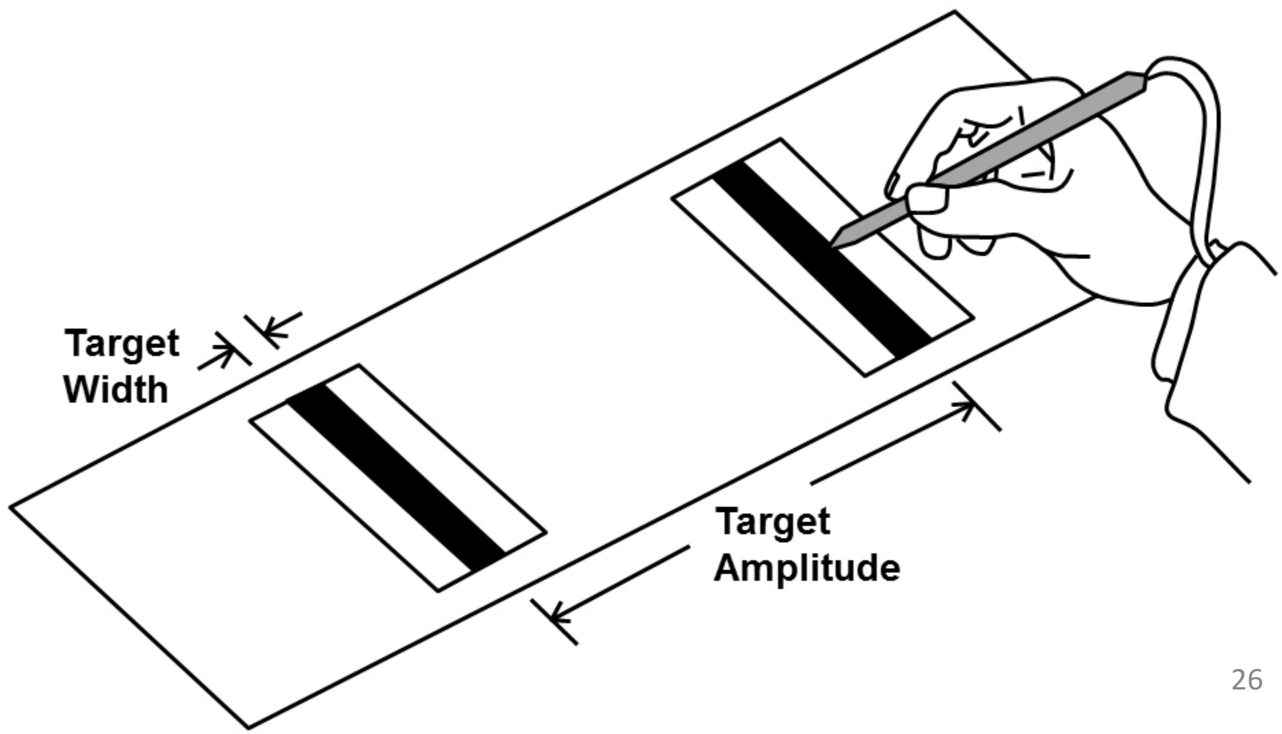


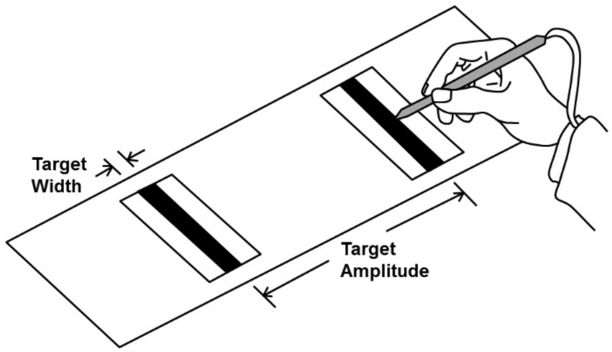
http://www.yorku.ca/mack/hci1992-f1.jpg

Fitts' Law [Fitts, 1954]

$$T = k \cdot \log_2\left(\frac{G}{W}\right)$$

Time to select target





Fitts' Law

[Fitts, 1954]

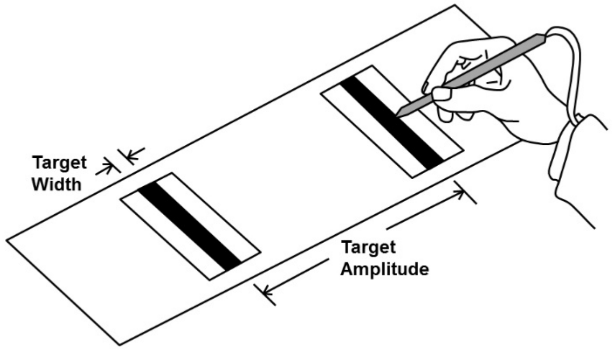
$$T = k \cdot \underbrace{\log_2\left(\frac{G}{W}\right)}_{\text{Index of difficulty}}$$

Gap distance

Width

Time to select target

Constant (determined empirically)



Fitts' Law

[Fitts, 1954]

$$T = k \cdot \log_2 \left(\frac{G}{W} \right)$$

Gap distance

Width

Time to select target

Constant (determined empirically)

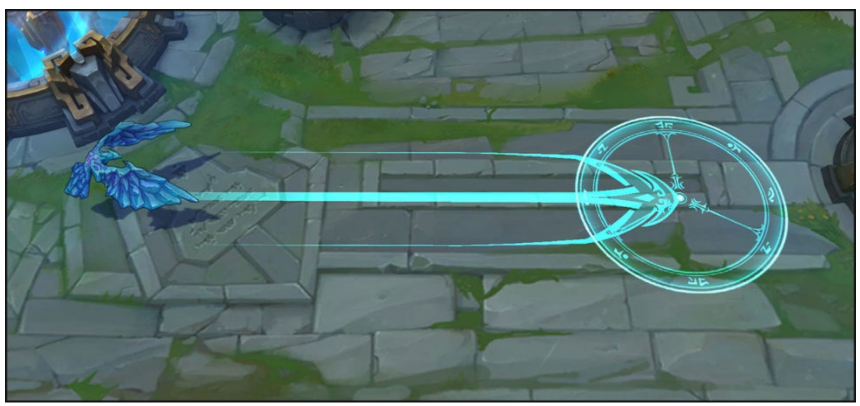
Index of difficulty

Robust under many conditions: limbs (hands, feet, lips, head-mounted sight, eye gaze), input devices (mouse, stylus), environments (e.g., underwater), and users (young, old, special needs, impaired)
Missing? → 2d, moving target, with delay

Why Moving Target Selection?

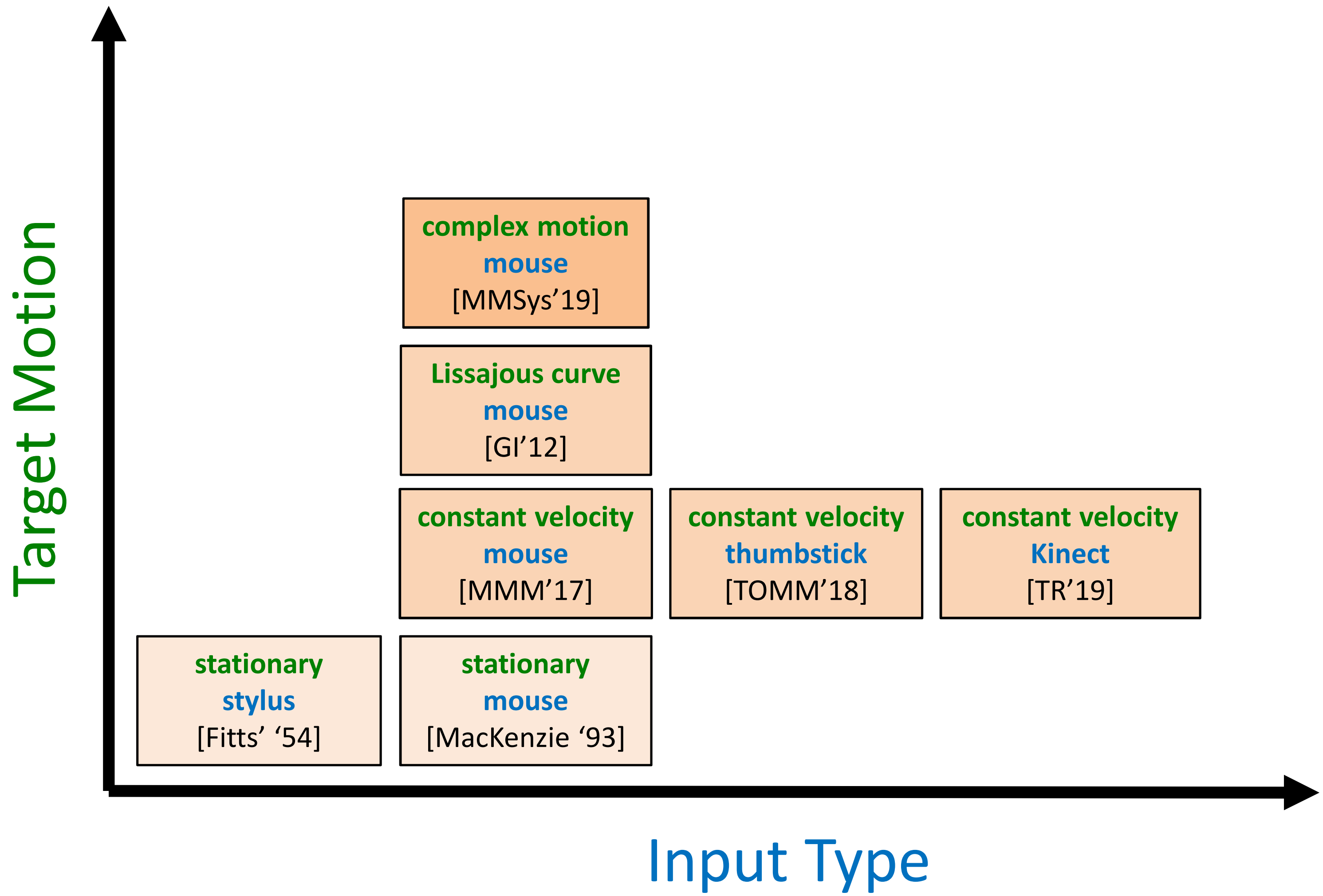
Call of Duty [Activision, 2003]

Duck Hunt [Nintendo, 1984]



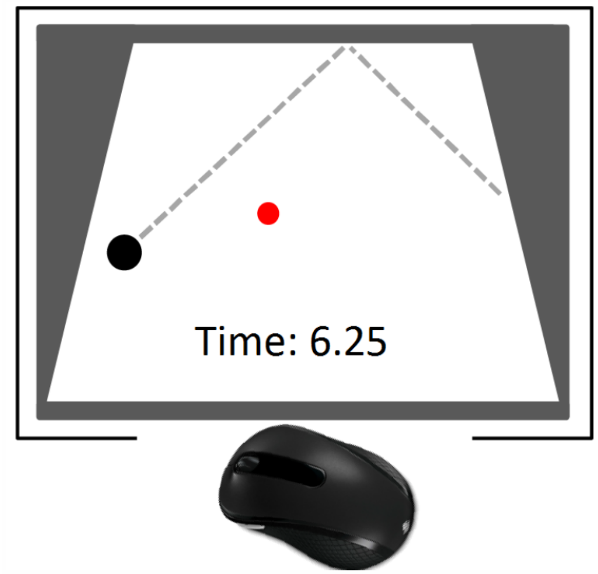
League of Legends [Riot Games, 2009]

Moving Target Selection with Latency



User Studies

- Time to select moving target with mouse
- Vary:
  - Target speed
  - Target motion type
  - Added latency



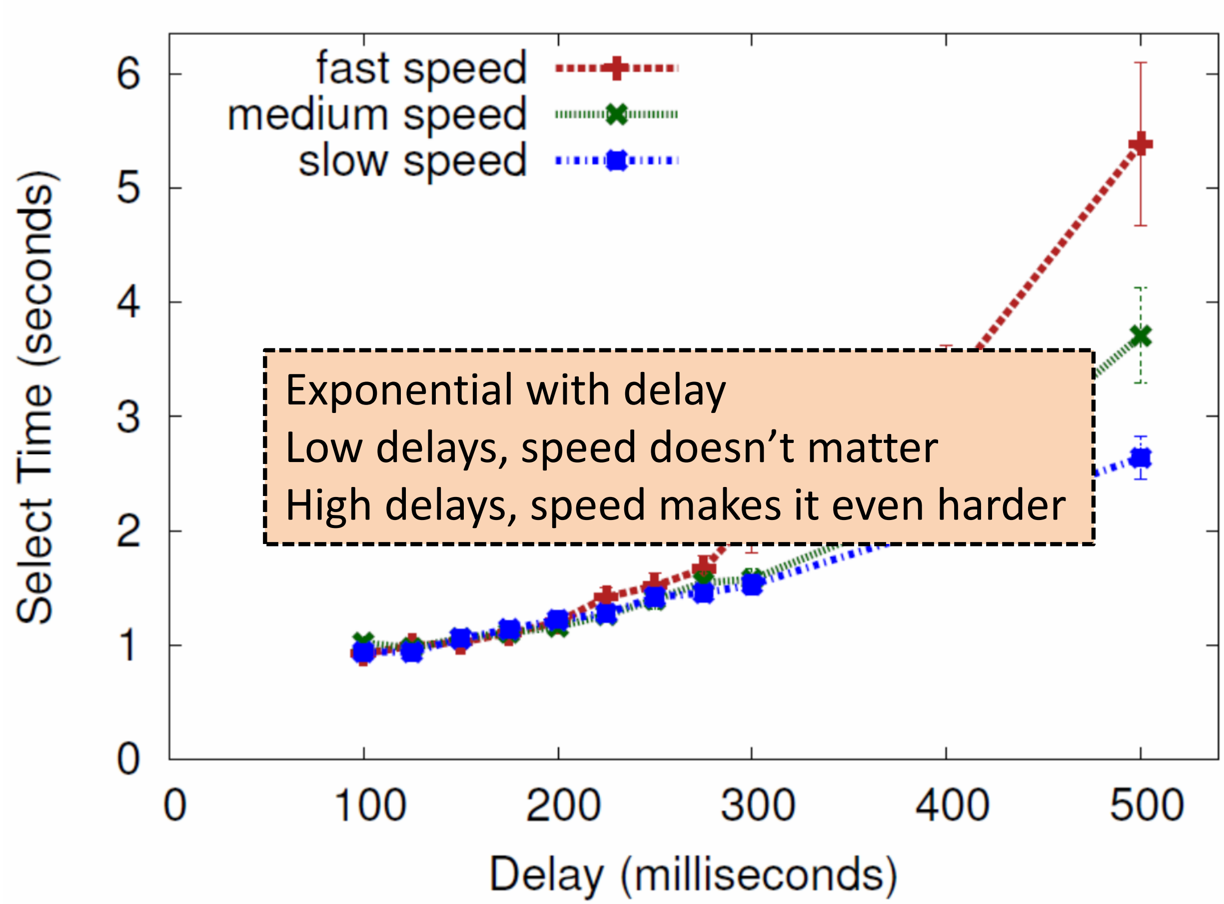
Objective

- User Performance
  - Time to click
  - Distance from target

- Quality of Experience
  - Responsiveness
  - Notice latency

Subjective

Selection Time versus Latency – Measurement



[Claypool et al., 2017]

Selection Time versus Latency – Model

$$T = k_1 + k_2 e^D + k_3 e^S + k_4 e^D e^S$$

Time to select target

Exponential with delay

Exponential with speed

speed-delay interaction term

Selection Time versus Latency – Model

$$T = k_1 + k_2 e^D + k_3 e^S + k_4 e^D e^S$$

[Claypool et al., 2017]

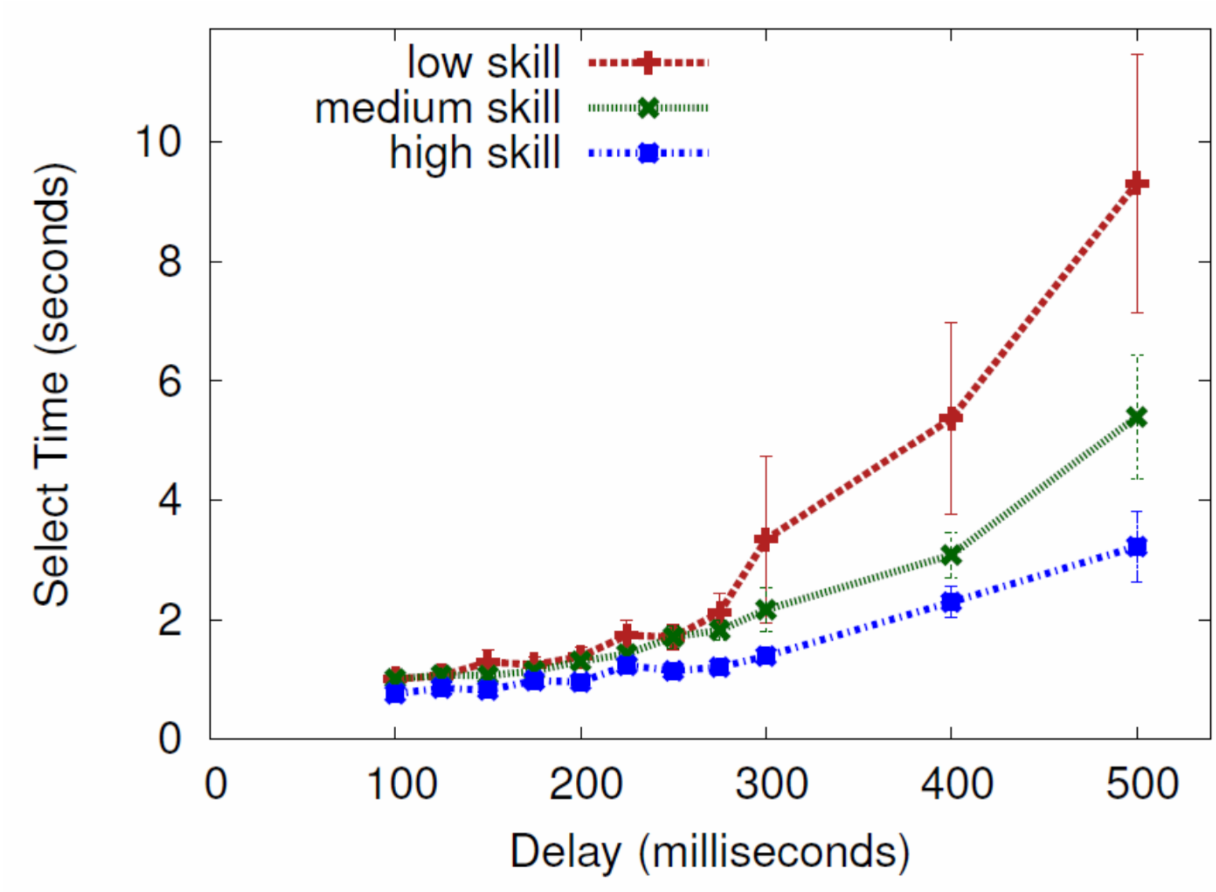
Factor	Mean	StDev
Delay	245 milliseconds	114
Speed	300 pixels/second	122

$$T = 1 + 0.2e^d - 0.04e^s + 0.1e^d e^s$$

$$s = \frac{S-300}{122} \qquad d = \frac{D-245}{114}$$

R^2 0.97
F-stat 328
$p < 2.2 \times 10^{-16}$

Selection Time versus Delay – By Skill



[Claypool et al., 2017]

Delay affects all skill levels
Low skill most impacted, high skill least impacted

Outline

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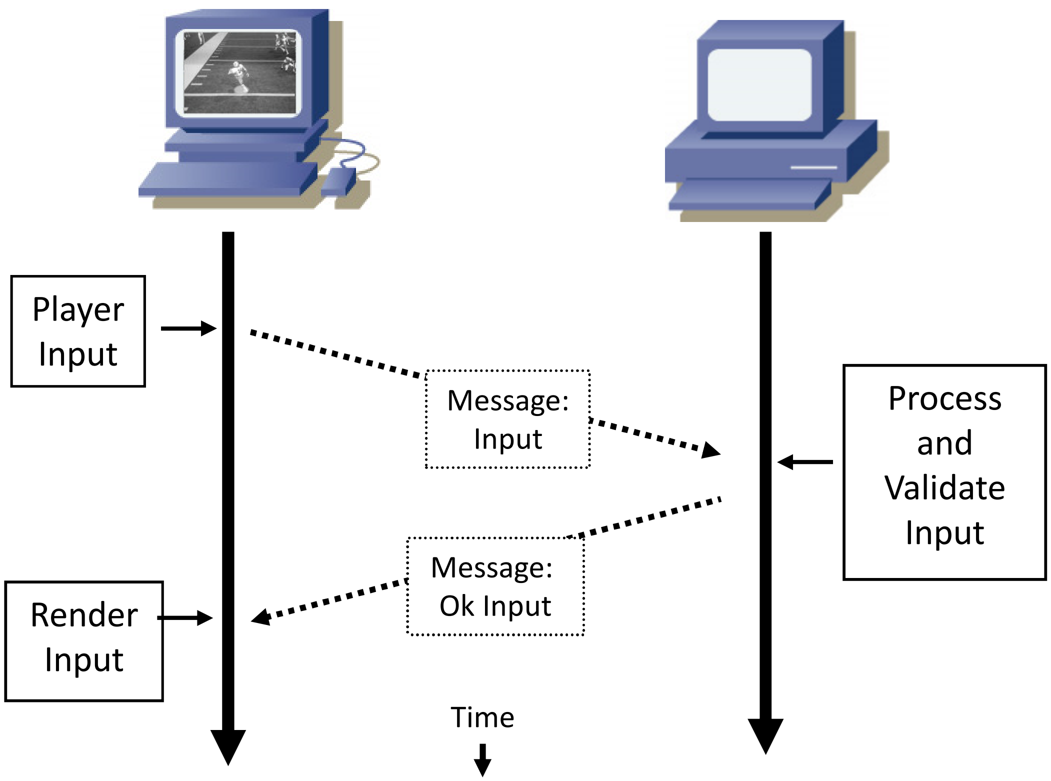
No Compensation for Latency

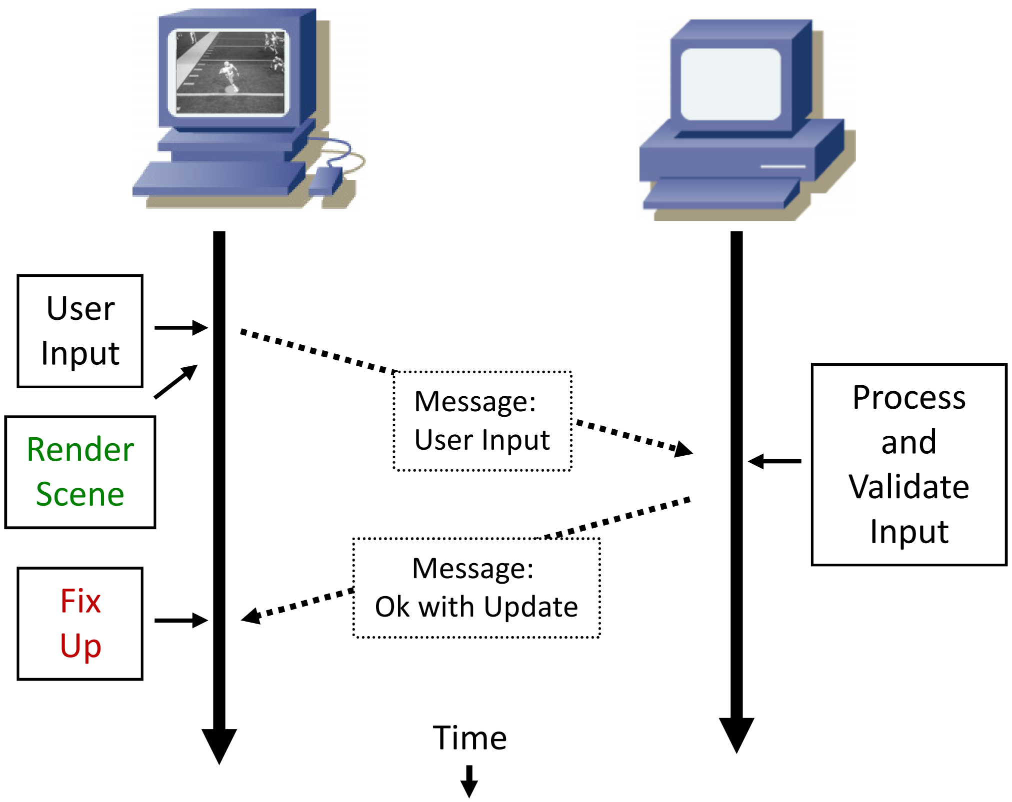


Client

- Send user input to server
- Wait for server game data
- Render scene
- Repeat

Player suffers from degraded responsiveness.

Compensating for Latency – Player Prediction



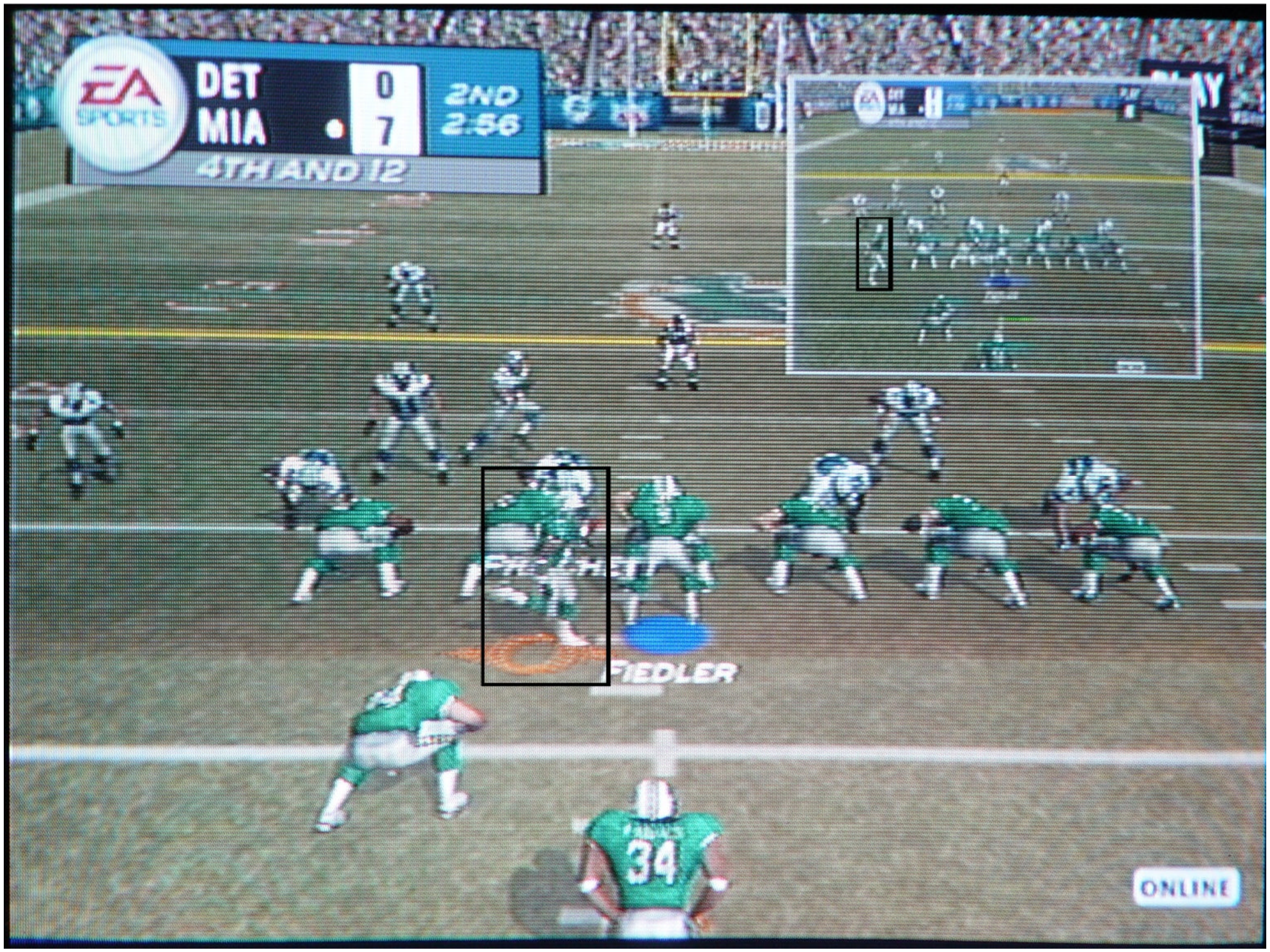
Client

- Send user input to server
- Determine local game state
- Render scene
- Receive updates from server
- Fix up any discrepancies
- Repeat

Potentially, *tremendous* benefit. Render as local.
But Render then Fix Up → may increase inconsistency

[Armitage et al, 2006]

Example of State Inconsistency



[Nichols and Claypool, 2004]

Player Prediction Tradeoffs

- Tension between responsiveness (latency compensation) and consistency

Client uses prediction

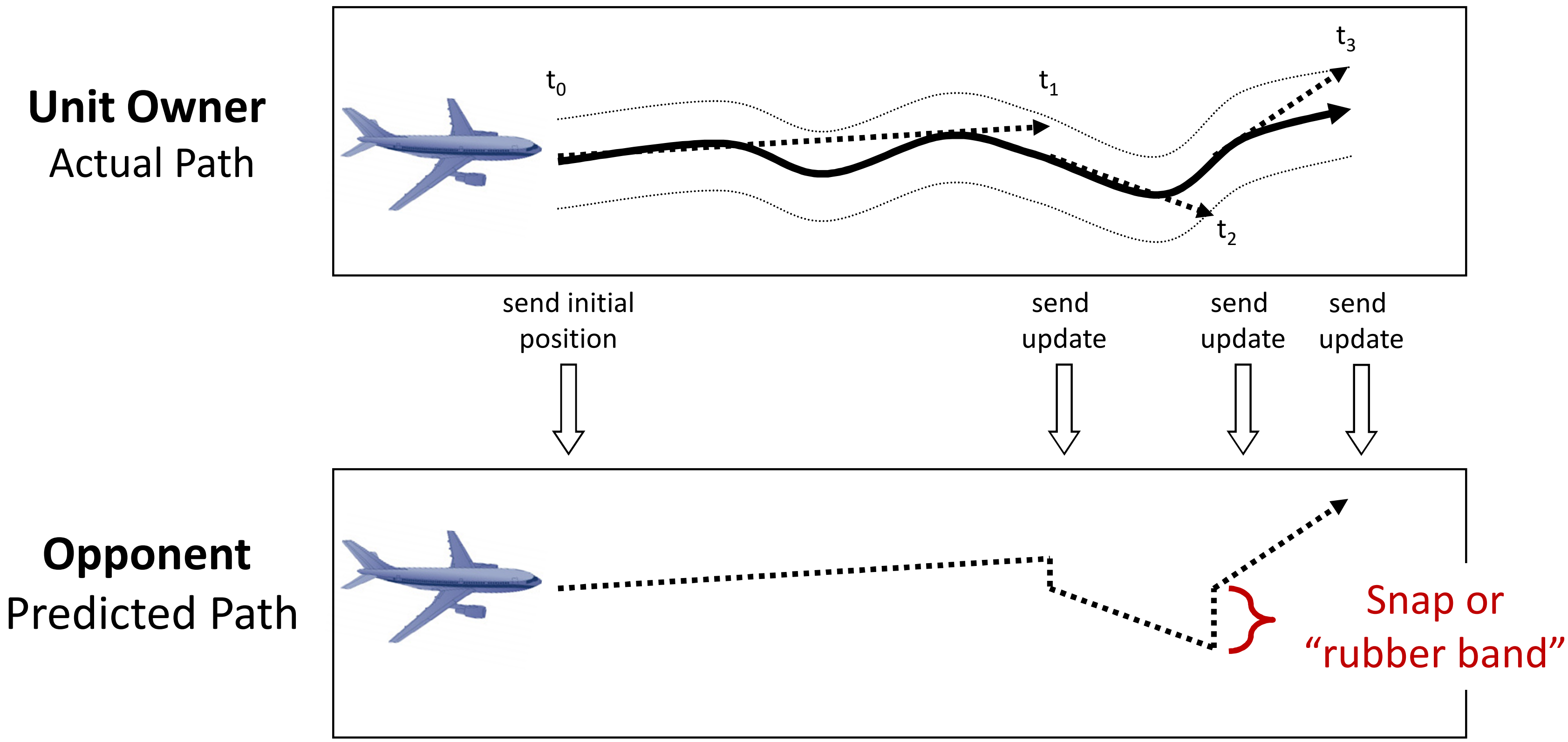
Client waits for server ok

More responsive,
Less consistent

Less responsive,
More consistent

Compensating for Latency – Opponent Prediction

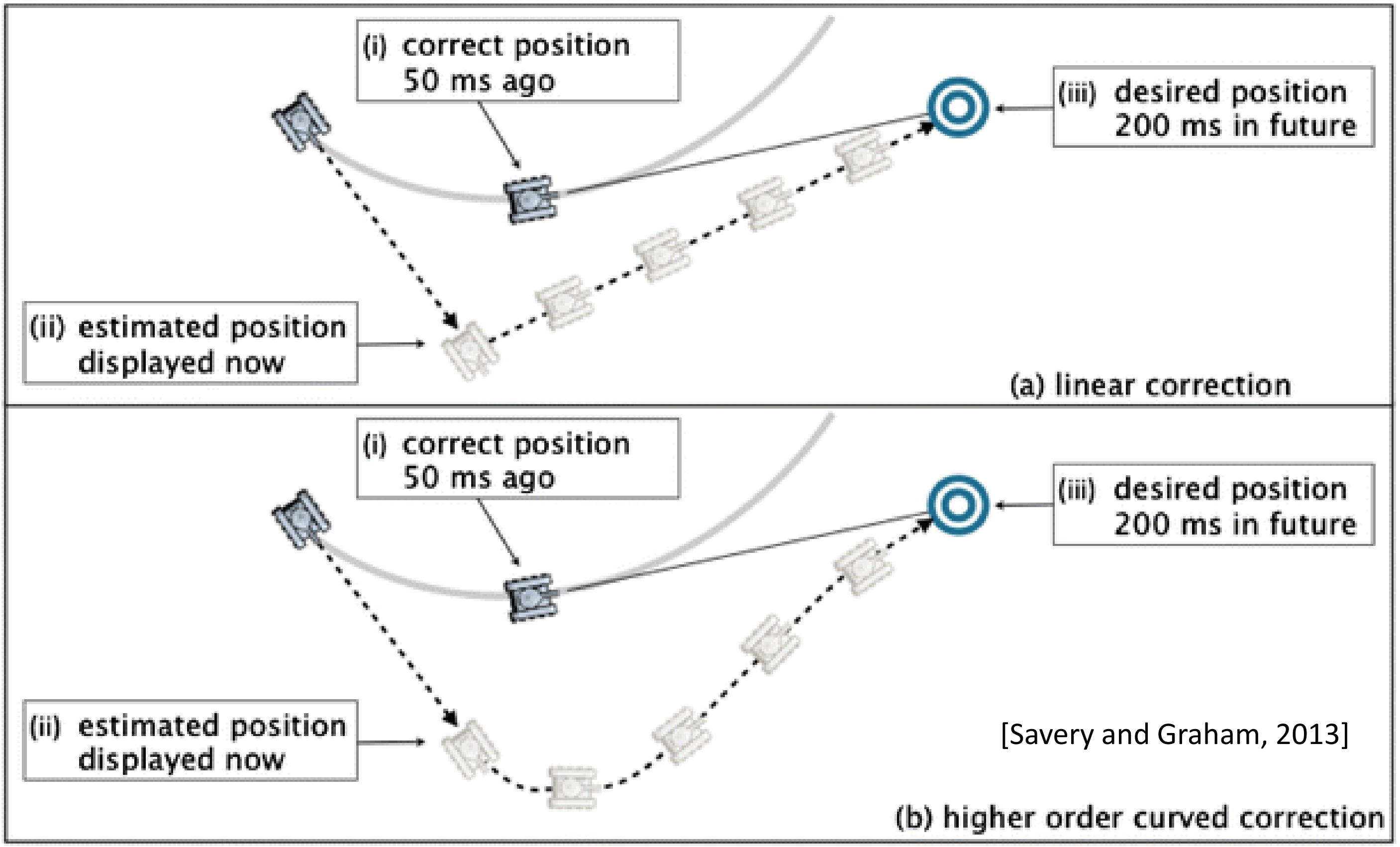
- Opponent sends position, velocity (maybe acceleration)
- Player predicts where opponent is



Client must Fix Up state when receive update

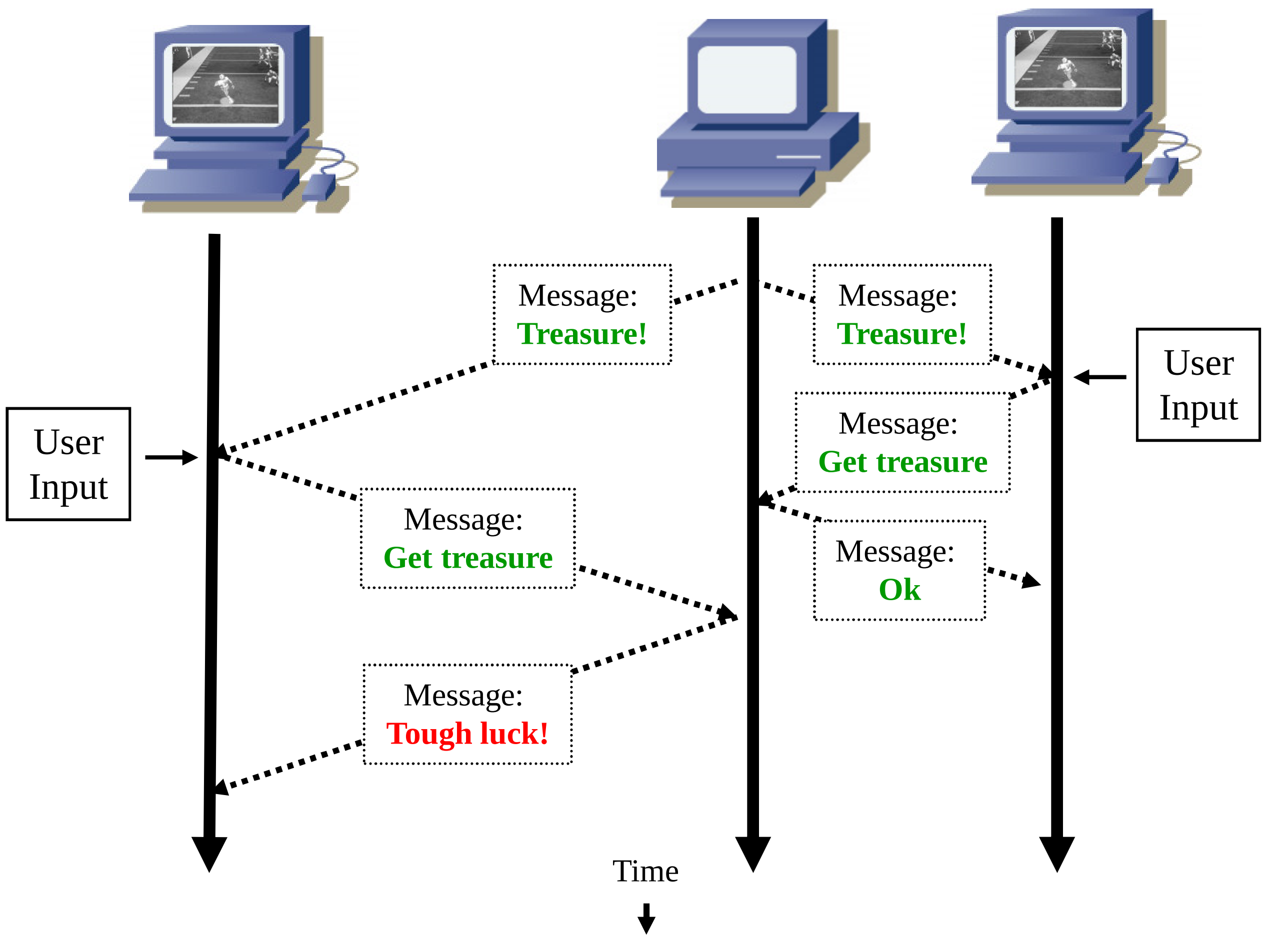
[Armitage et al, 2006]

Compensating for Latency – Opponent Prediction



Unfortunately, Player Prediction and Opponent Prediction **cannot** be used for cloud-based games

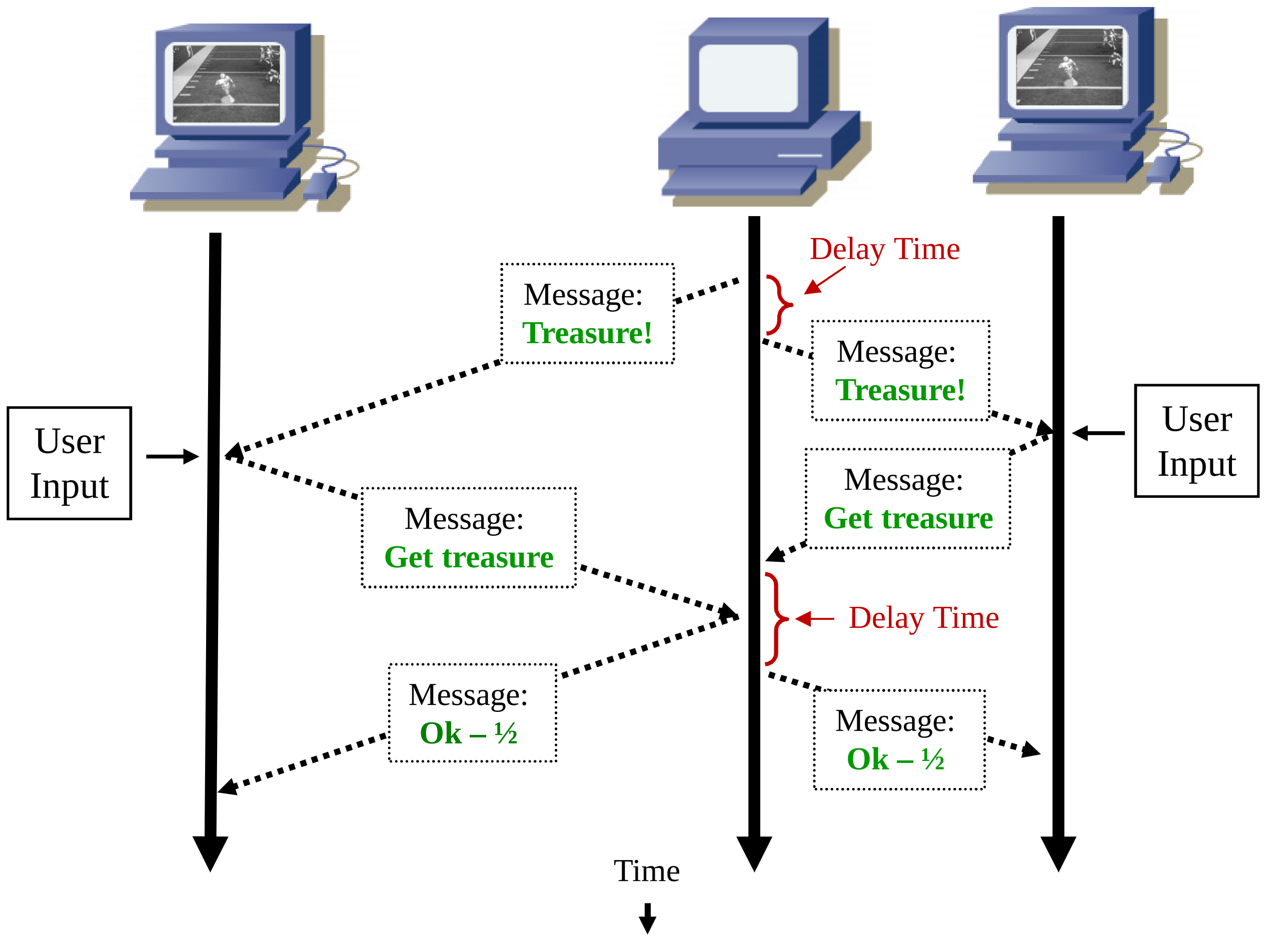
Why Else Does Latency Matter?



Latency affects *fairness*

Solution? Manipulate time:
Time Delay and Time Warp

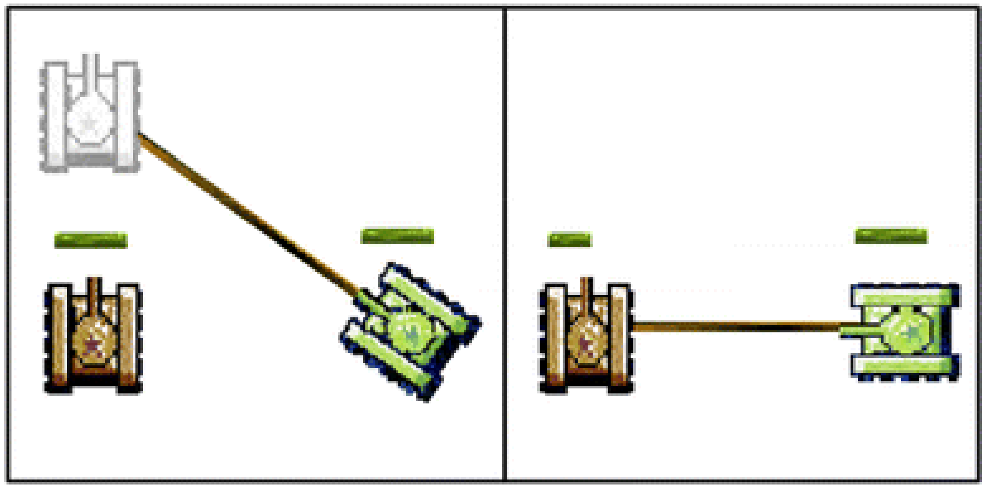
Compensating for Latency – Time Delay



Improves fairness.

But **all** players delayed by highest latency

Example of Shooting with Latency

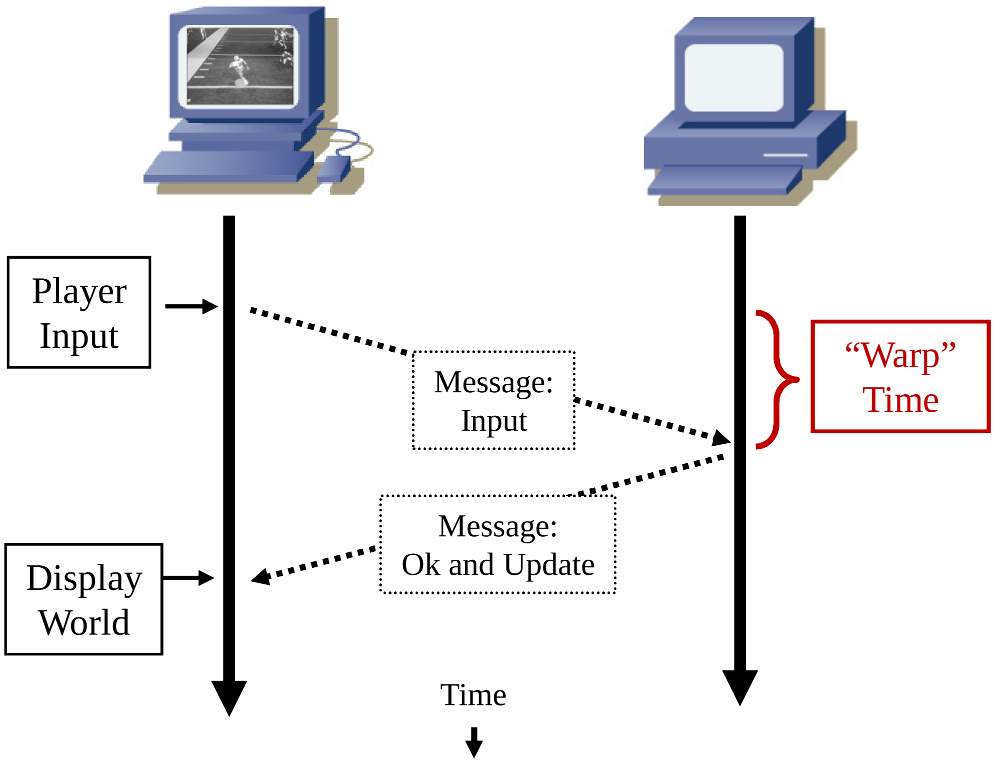


(a) Leading target (b) Aiming at target

[Savery and Graham, 2013]

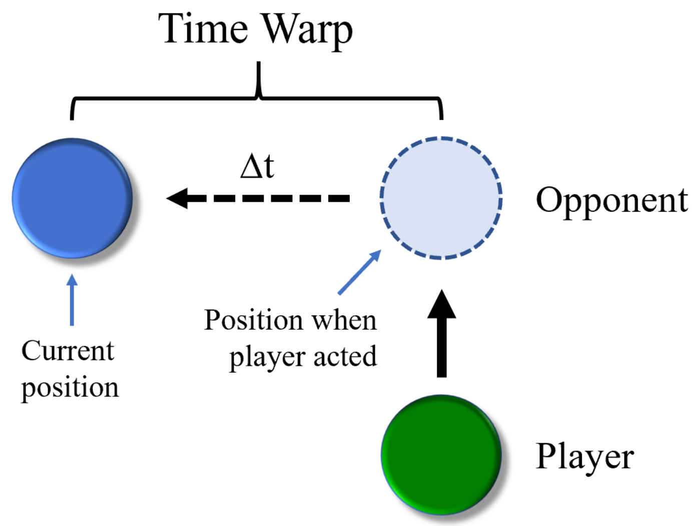
Player needs to predict **server** world state

Compensating for Latency – Time Warp

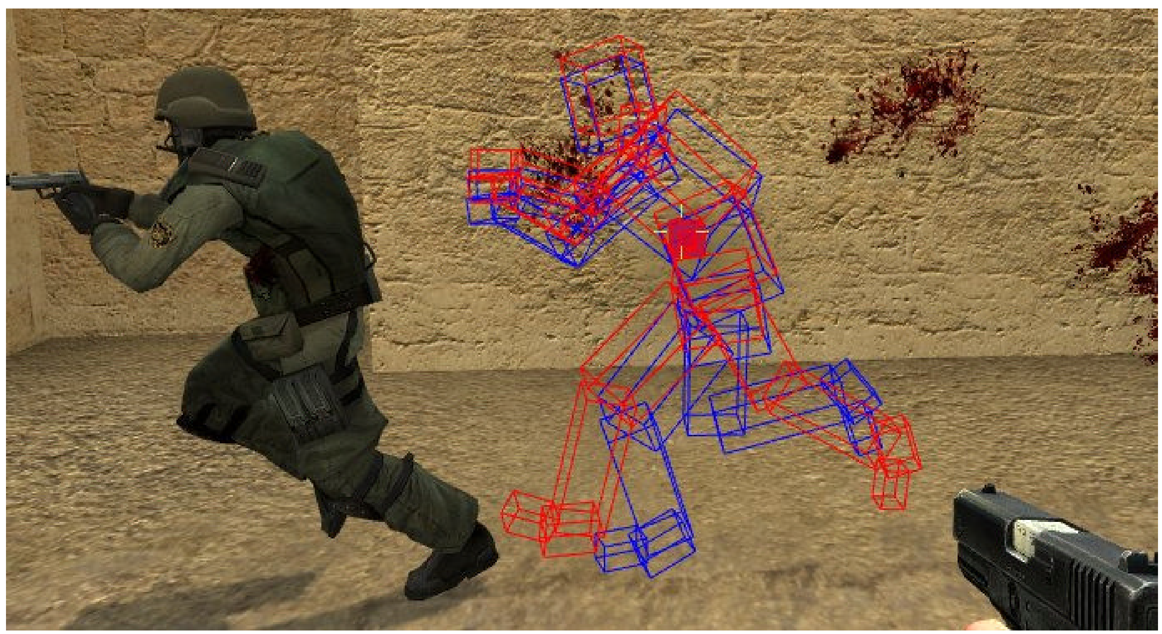


Player can act on **client** world state

Time Warp Example



Counterstrike
[Valve, 2000]



https://developer.valvesoftware.com/w/images/c/ca/Lag_compensation.jpg

A Taxonomy of Latency Compensation Techniques

Client Only	Client & Server	Server Only
Player Prediction	Parallel Worlds	Time Manipulation
Opponent Prediction	World Adjustment	- Warp
- Interpolation	Control Assistance	- Delay
- Extrapolation		
Concealment		

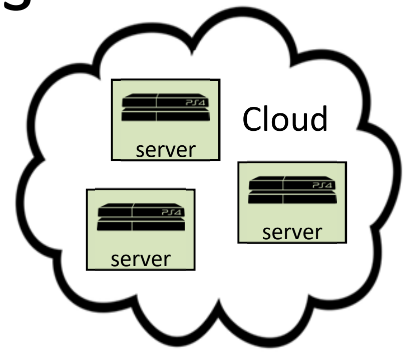
Can be done for cloud-based games

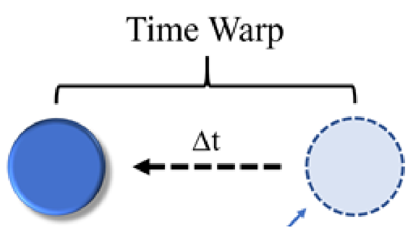
Conclusion

- Cloud-based games present challenges
  - Capacity and Latency
- Latency can kill (your fun!)
  - Responsiveness, consistency, fairness
- Measurement and models to better understand and inform

$$T = k_1 + k_2 e^D + k_3 e^S + k_4 e^D e^S$$

- Latency compensation can help
  - Time manipulation can work for cloud-based games





Future Work

- Apply models to game design
- Measure effects of latency on other game actions
  - Navigation

- Develop (and measure) new latency compensation techniques
  - Cloud-based games
- Cloud-based game systems for experiments

Acknowledgements

- Students
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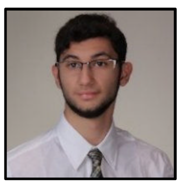
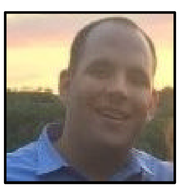
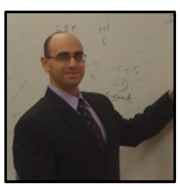
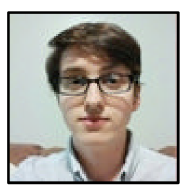
  - Bhon Bunnag
  - Chai Ekkaewnumchai





- Colleagues
  - Ragnhild Eg
  - Kjetil Raaen
  - Kajal Claypool
  - David Finkel
  - Andy Cockburn
  - Carl Gutwin



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Lag Can Kill – Measuring, Modeling and Mitigating the Effects of Latency on Game Players

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Extra Slides

Latency and Interactivity

- Latency as low as 2 ms can be perceived by humans [NG-lag-12]
- End-to-end latency around 50 ms is known to affect performance in mouse-based pointing tasks [mackenzie-ware-93, latency-pointing-09, MacKenzie-3d-09, deber-lag-15]
- Measure of end-to-end latency on modern operating systems average from 45 to 85 ms (depending on the operating system and toolkit) [OS-lag-15]

Extensions to Fitts' Law

- One dimension → *2 dimensions* [MacKenzie, 1992]
  - Time proportional to area ("effective width")
  - Target shape mostly irrelevant
- No added delay → *transmission delay* [Hoffman, 1992] [MacKenzie, 1993]
  - Time linear with delay
- Stationary target → *moving target* [Jacacinski, 1980] [Hoffman, 1991] [Hajri, 2011]
  - Add speed to index of difficulty
  - Time linear *or* exponential with speed
- Missing? → delay and moving target selection

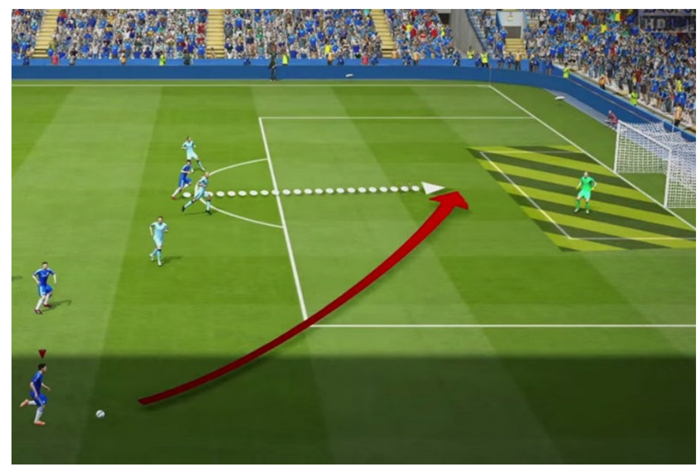
→ Fitts-type law for game actions!

Complex Motion?

[*Mario Kart 8*, Nintendo, 2014]

[*Madden NFL*, EA, 2016]

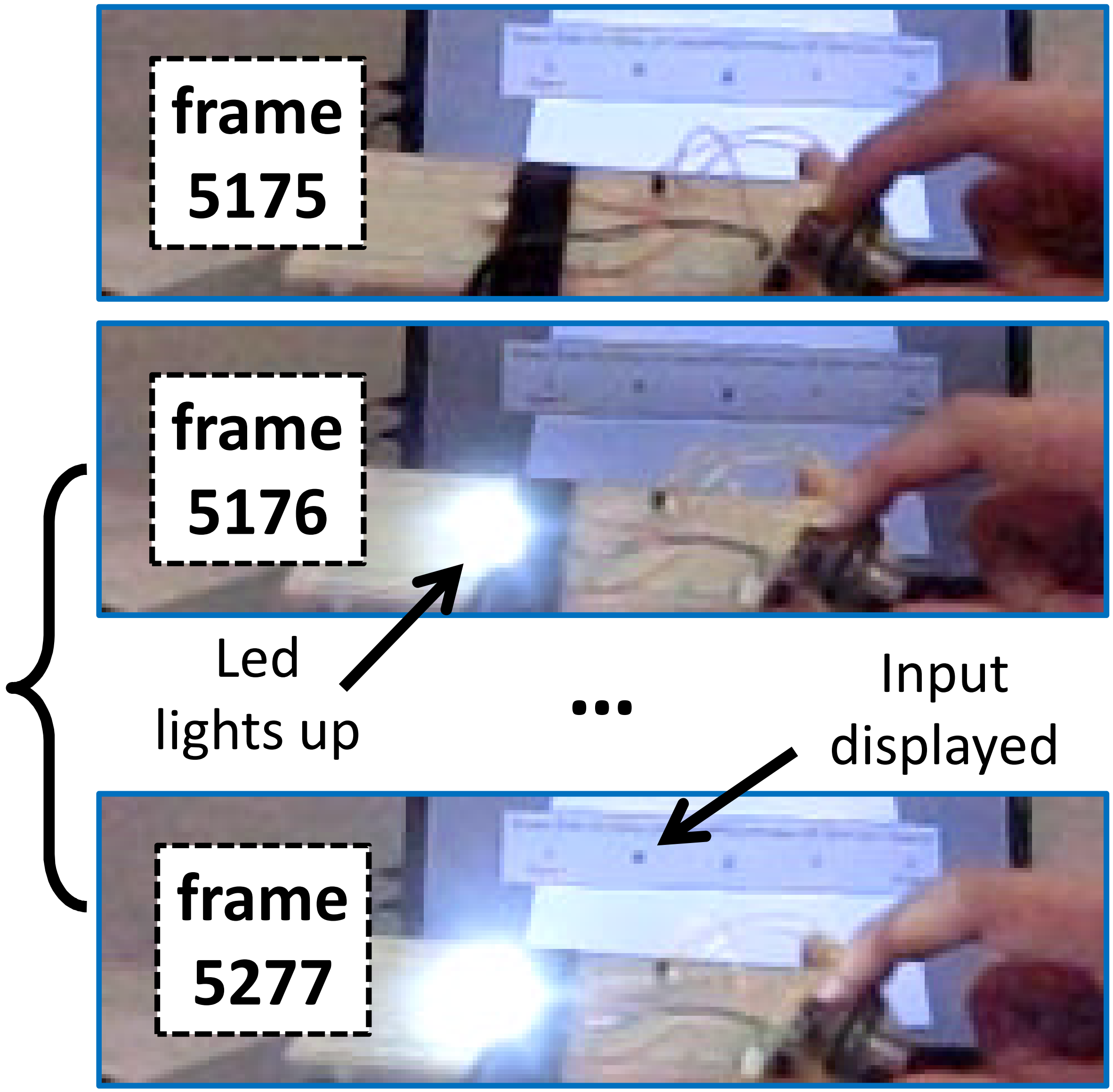
[*Battlefield 1942*, EA, 2002]



[*FIFA*, EA, 2016]

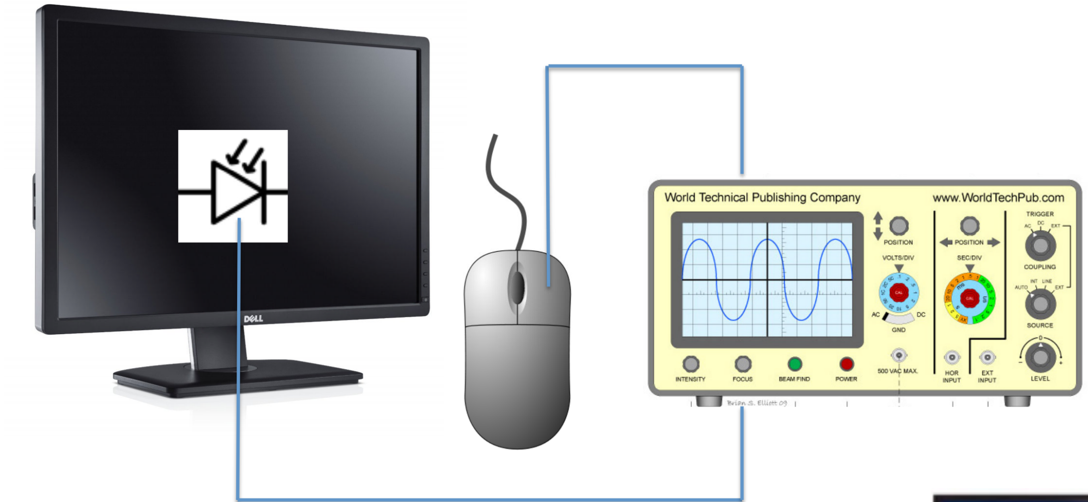
Measuring Local Latency

Base system (local) latency

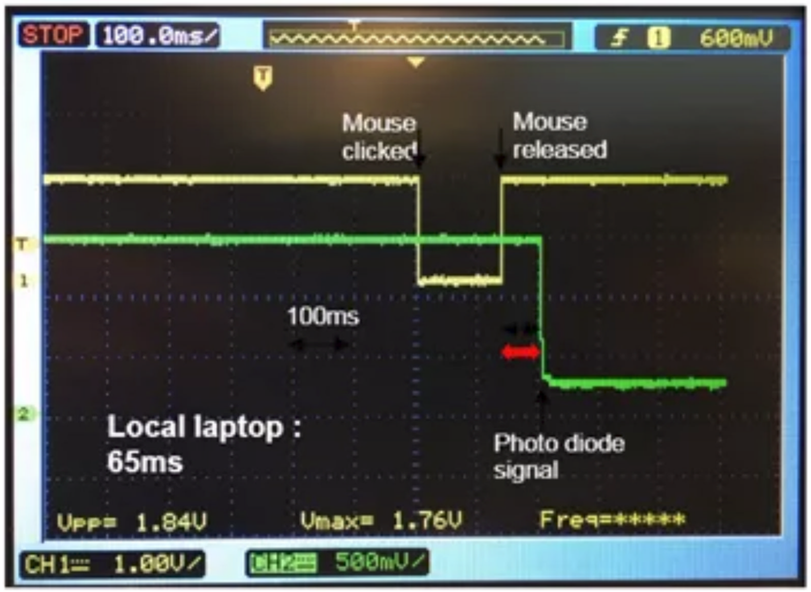


Solder wire to mouse
→ Click lights up bread board
Record with high frame rate camera (Casio EX-ZR200 – 1000 f/s)

Measuring Local Latency

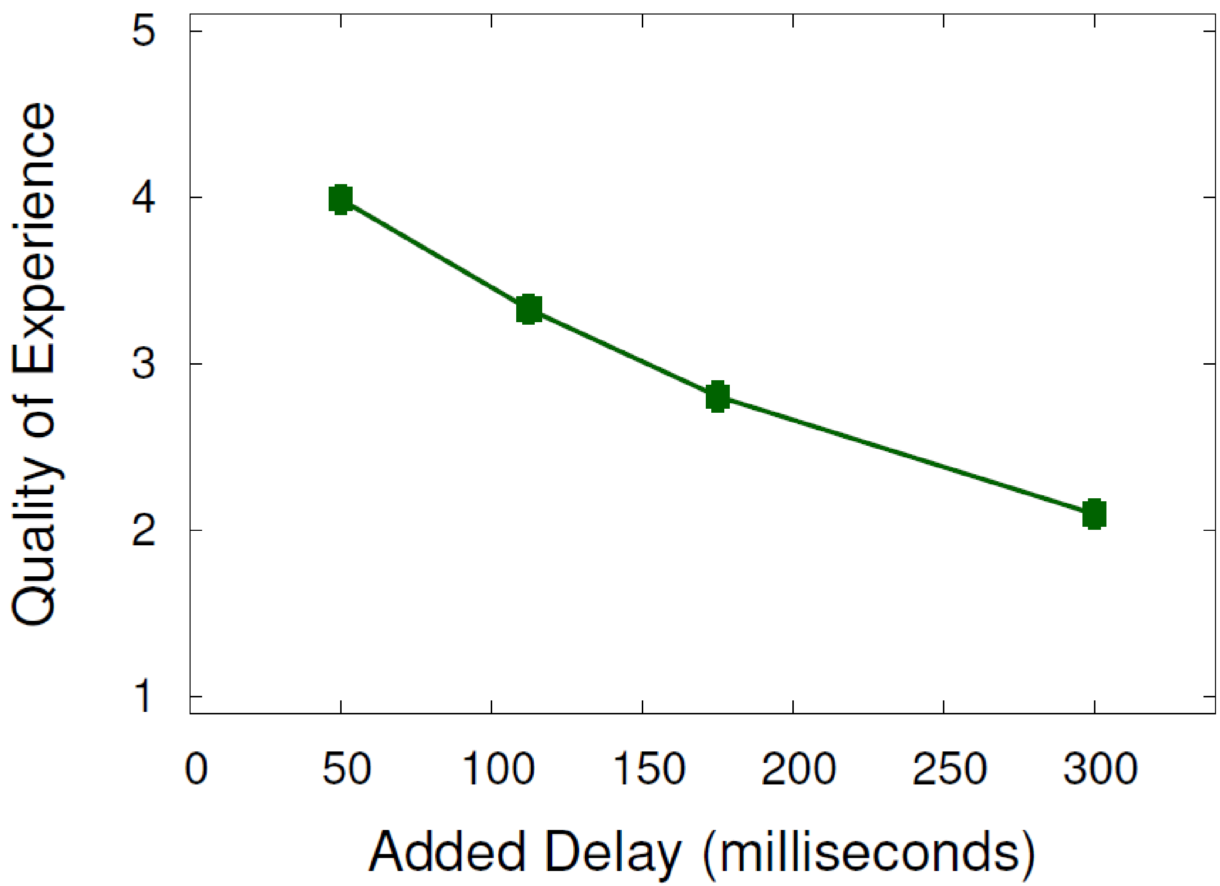


https://www.simula.no/sites/default/files/publications/files/input_delay_demo.pdf



https://i0.wp.com/www.virtualexperience.no/wp-content/uploads/2016/03/030716_1859_HowtouseCli2.png?zoom=7.5&w=678

Quality of Experience



Linear/logarithmic decrease with delay

A Taxonomy of Latency Compensation Techniques