Inferring and Comparing Game Difficulty Curves using Player-vs-Level Match Data

Anurag Sarkar and **Seth Cooper**

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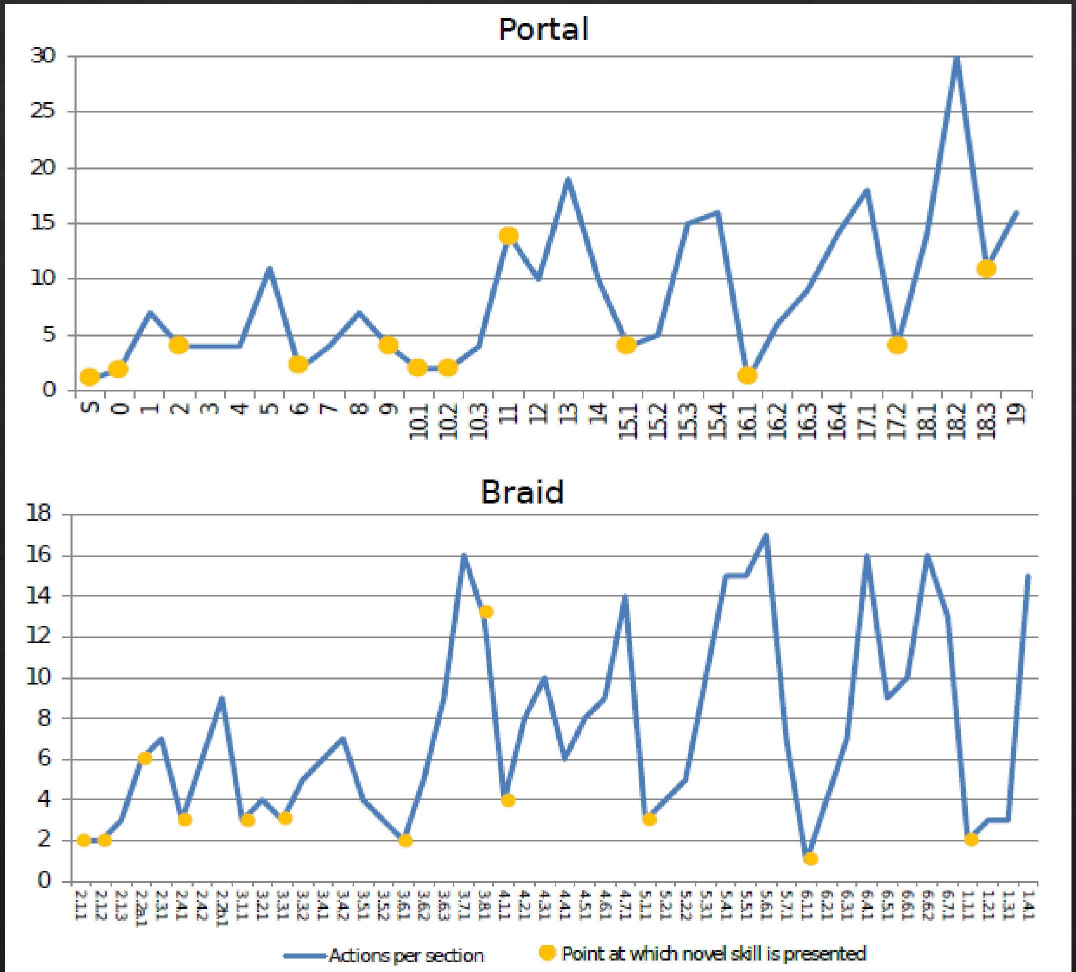
Difficulty Curve

- Defines how a game's difficulty changes over the course of gameplay



Linehan et al., 2014

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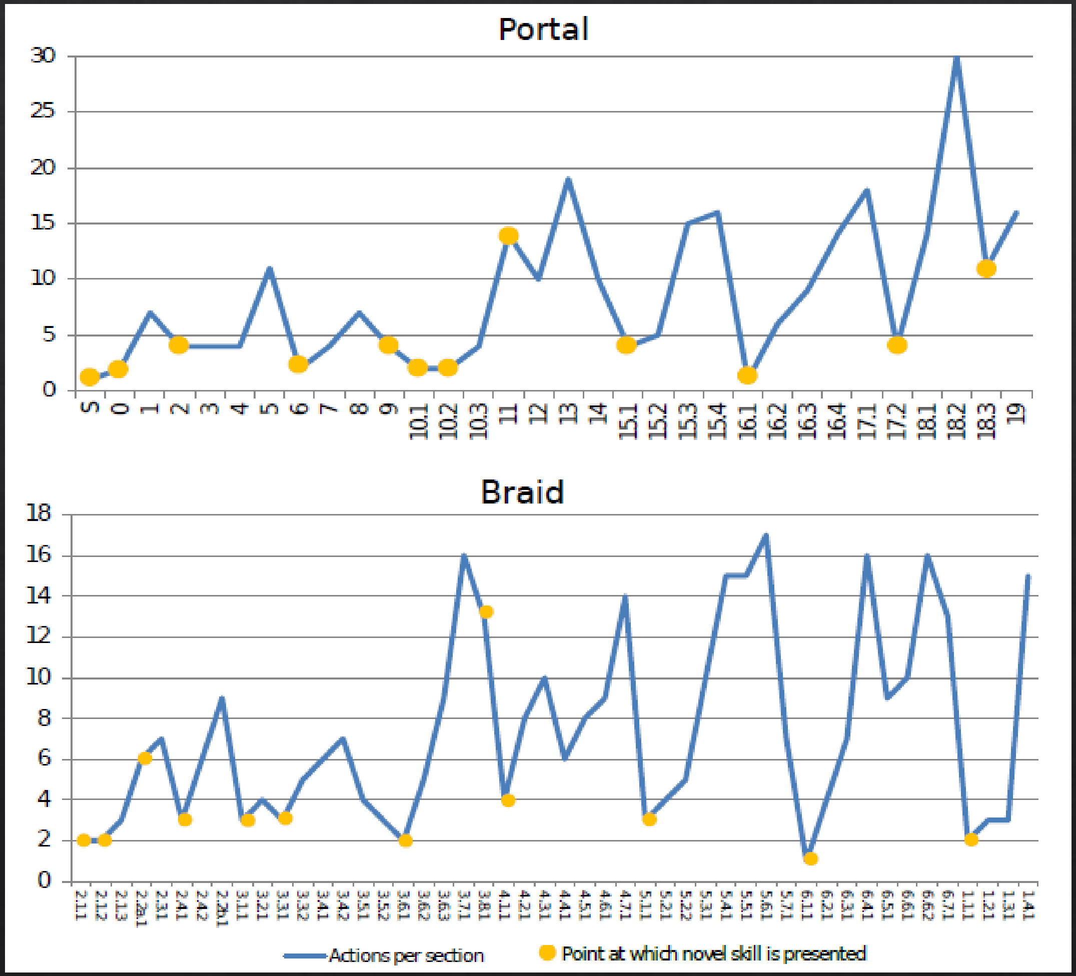
- Curves can be viewed as functions mapping from progression to difficulty



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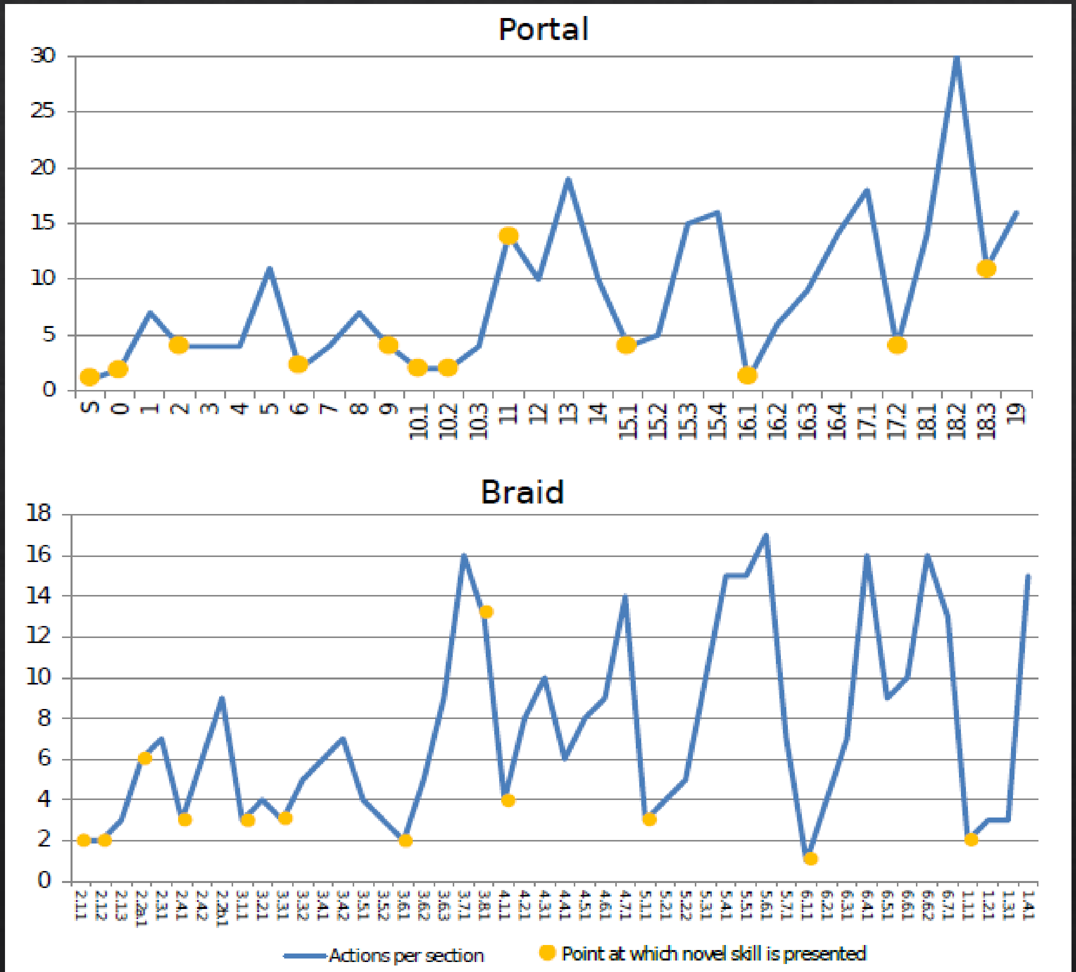
- Curves can be viewed as functions mapping from progression to difficulty
- Traditional methods of defining curves involve manual refinement through iterative playtesting



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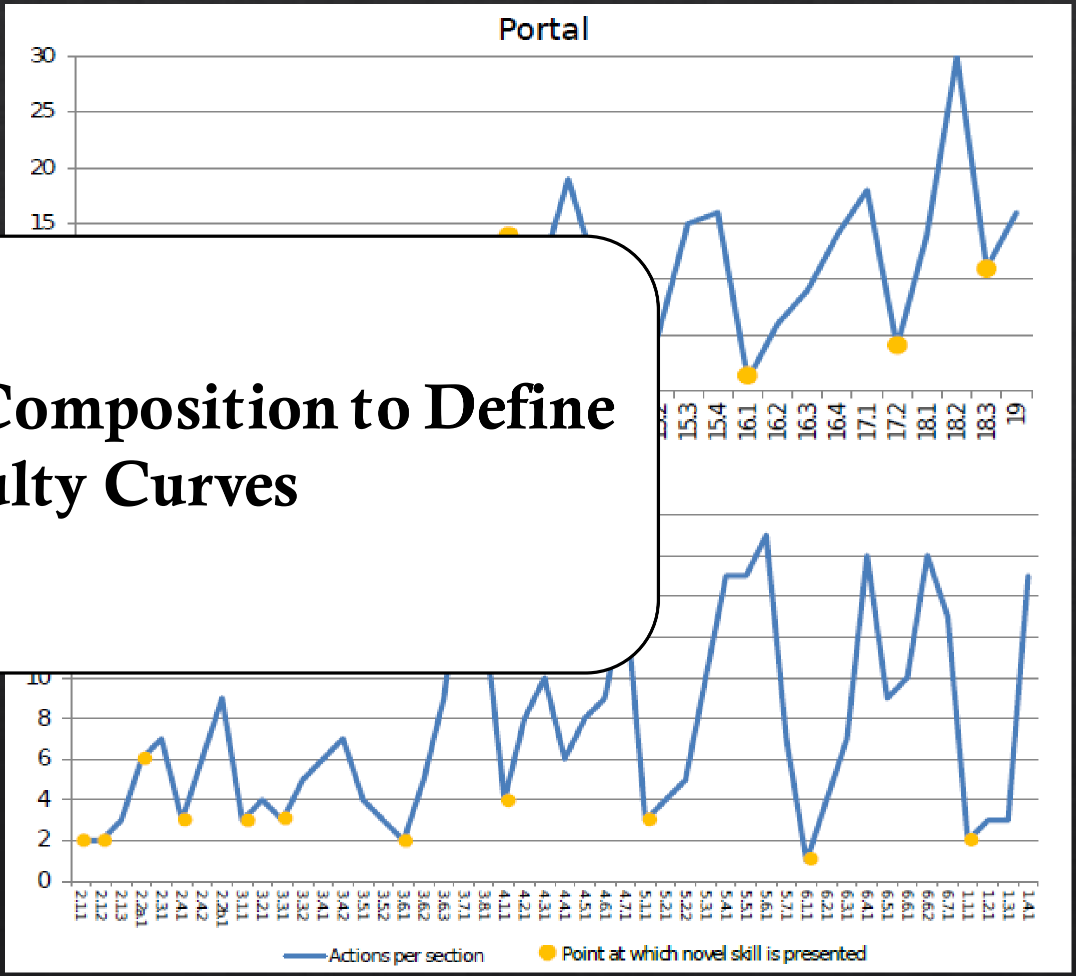
PRIOR WORK: Used Function Composition to Define and Transform Difficulty Curves



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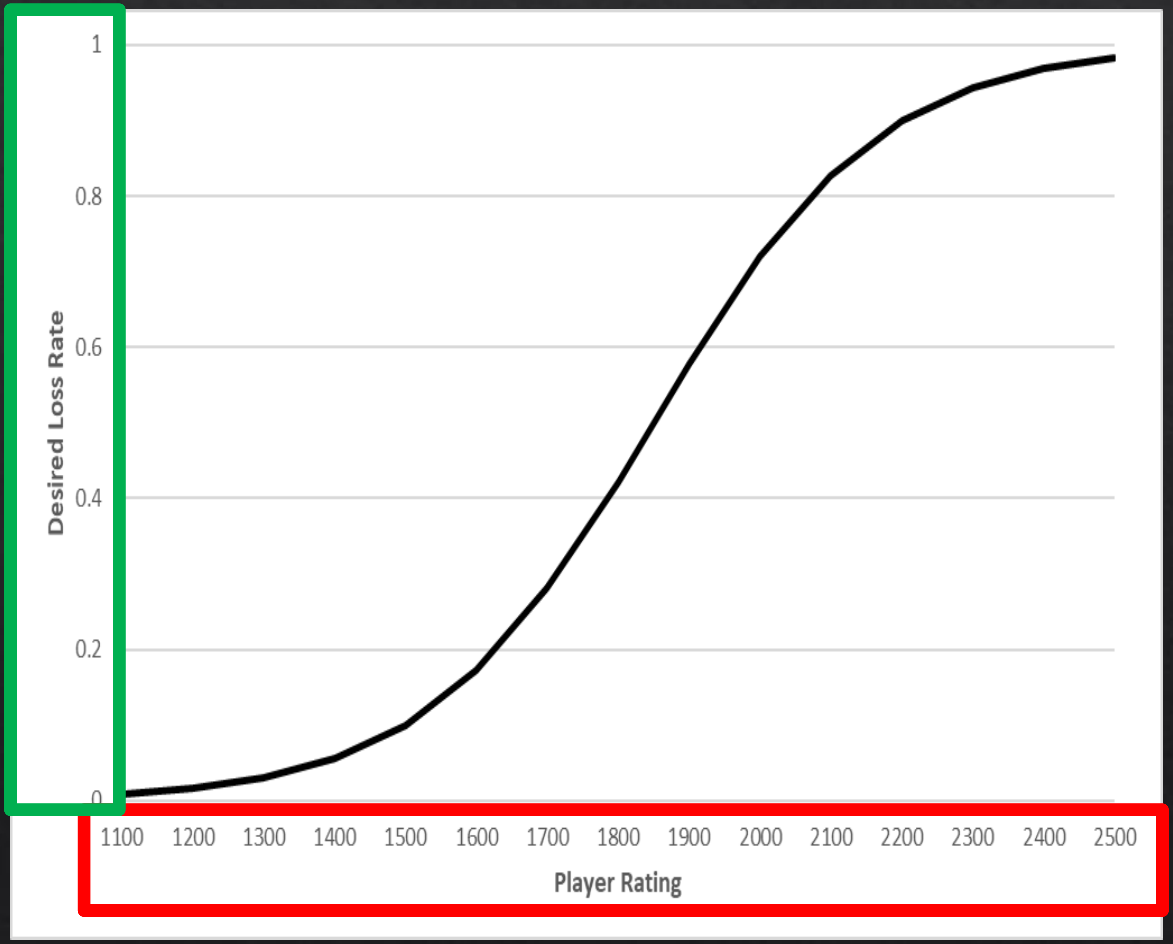
Difficulty Curves and Function Composition

Difficulty curve is a function mapping player skill (Glicko-2 rating) to difficulty (desired loss rate)

Baseline Curve	Description
$\boxed{f(x)} = \boxed{\frac{1}{1+e^{\alpha(\beta-x)}}}$	Logistic curve

Transformation Functions	Description
$t_\delta(x) = x + \delta$	Translate by δ
$s_{\sigma,c}(x) = \sigma(x - c) + c$	Scale by σ around c



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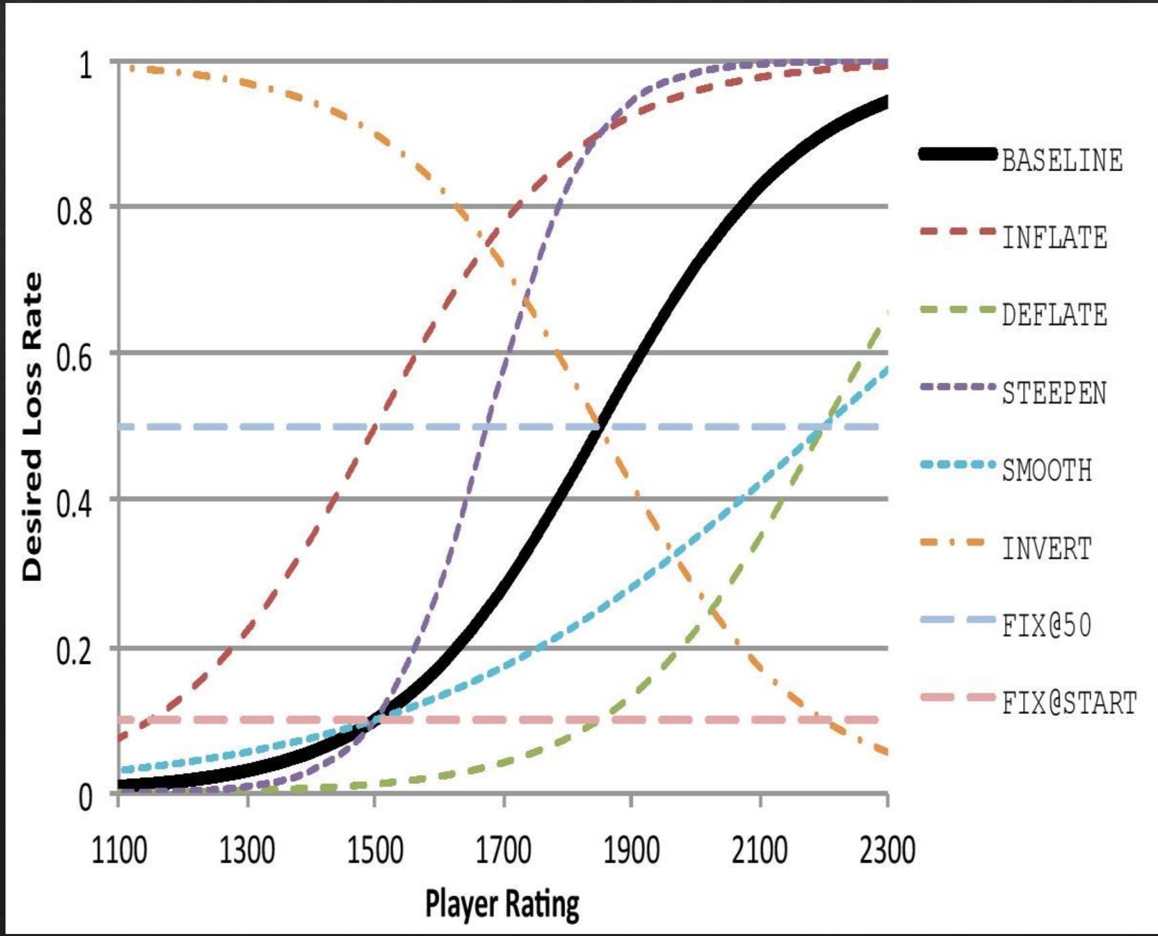
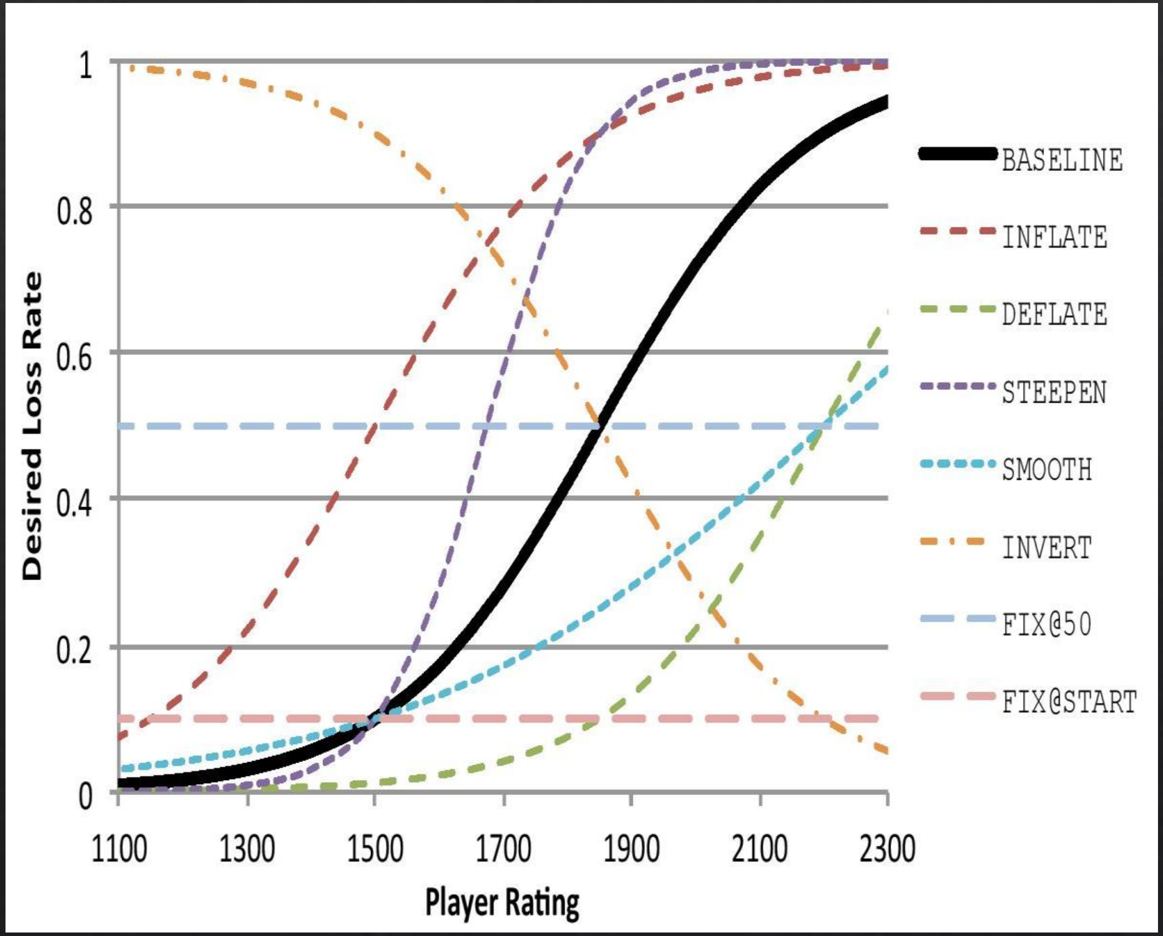


Sarkar and Cooper, "Transforming Game Difficulty Curves using Function Composition", CHI 2019

Difficulty Curves and Function Composition

- A formal approach to transforming a game's difficulty curve
- Modified baseline curve to generate new curves and precisely defined transformations
- Transformed curves impacted gameplay and some improved engagement



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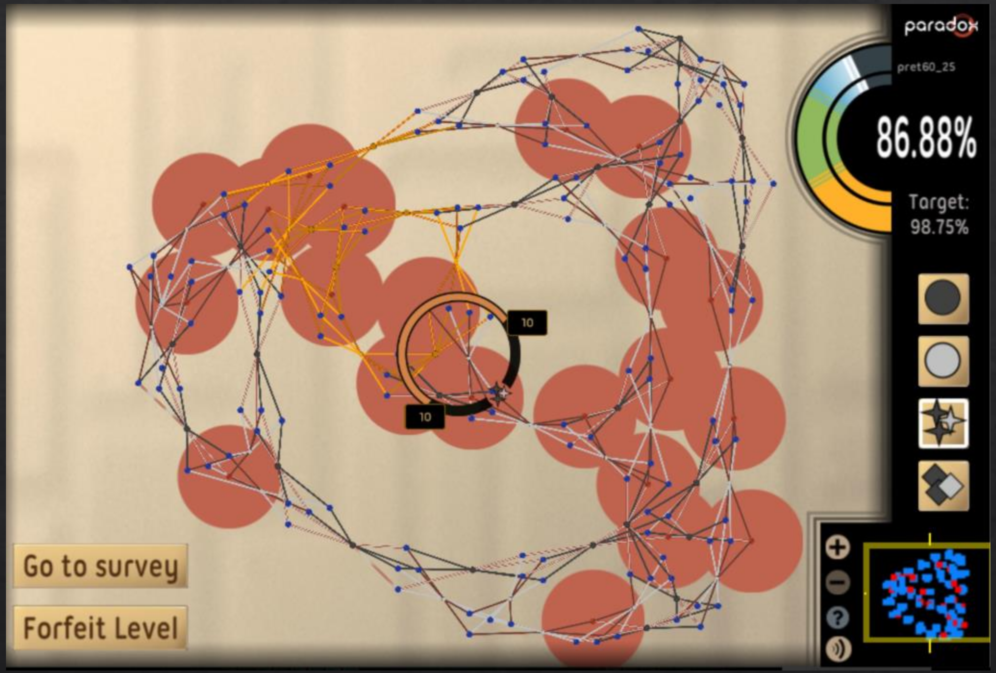
Drawback

- Only used with a single game *(Paradox)*
- Curves and transformations defined with respect to *Paradox's* DDA system and Glicko-2 ratings



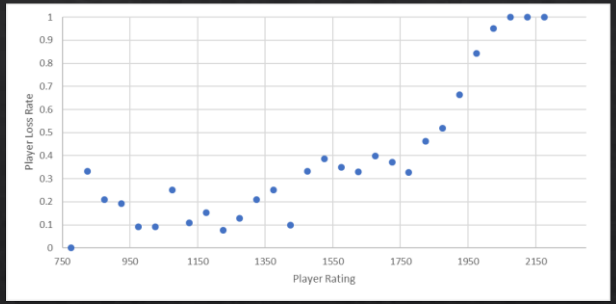
This Work

- Extends prior work to infer difficulty curves in a game-independent manner
- Uses same formulation for curves as prior work; enables use of function composition to compare curves from different games
- Applicable to games with either static or dynamic difficulty
- Introduces use of *phantom matches* (traditional playback does not work)

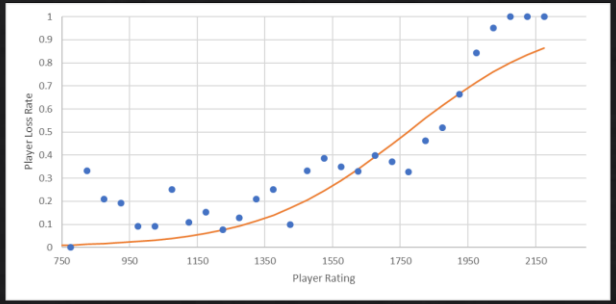
Approach

Timestamp	PlayerID	Level	Score
1535387920891	pl_1	hole6	1
1535387924221	pl_2	hole6	1
1535387944903	pl_3	hole6	1
1535387944959	pl_2	hole10	1
1535387945548	pl_1	hole10	1
1535387967345	pl_3	hole10	1
1535388008835	pl_2	flat50-50	0
1535388014748	pl_2	gen_tree_sa	1
1535388038068	pl_2	flat30-10	0
1535388046404	pl_1	flat50-50	0

- Collecting gameplay data



- Sampling from player skill to difficulty
  - Playback
  - Phantom match generation



- Fitting curves to sampled data

Gameplay Data

- Match data with instances of players playing levels treated as PvL matches
- Each entry consists of
  - Timestamp
  - Player ID
  - Level ID
  - Player win/loss (1/0)

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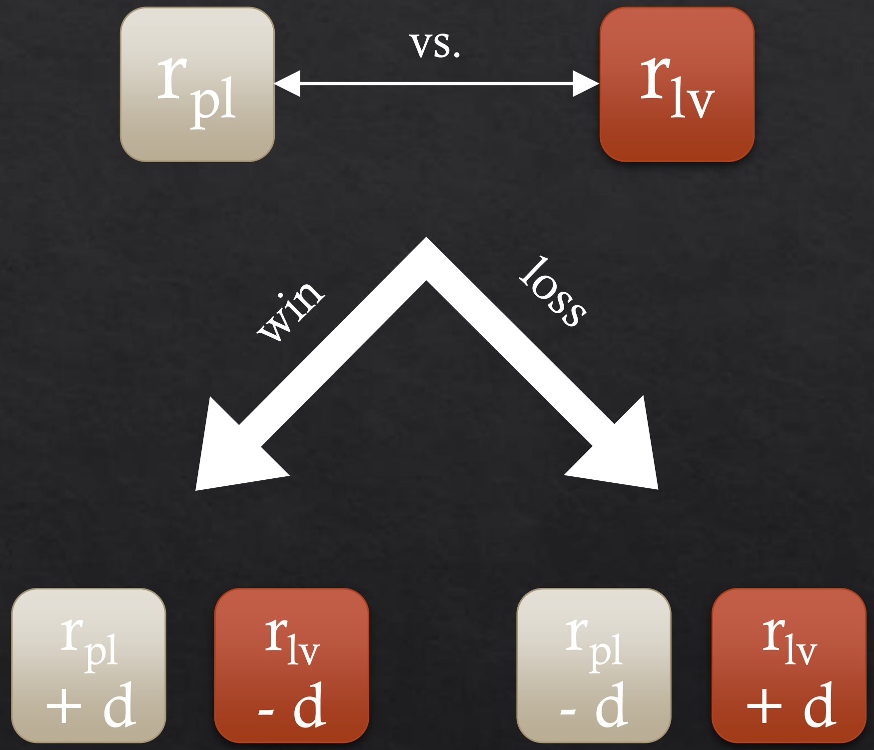
Sampling from Player Skill to Difficulty

- Want to determine game difficulty curve from this data i.e. fit curves to it
- In our formulation, curves are functions mapping player skill to difficulty
- To fit curves, we sample this mapping
  - Player skill → Glicko-2 rating
  - Difficulty → Player's loss rate
- Fitting curves involves playback and phantom match generation

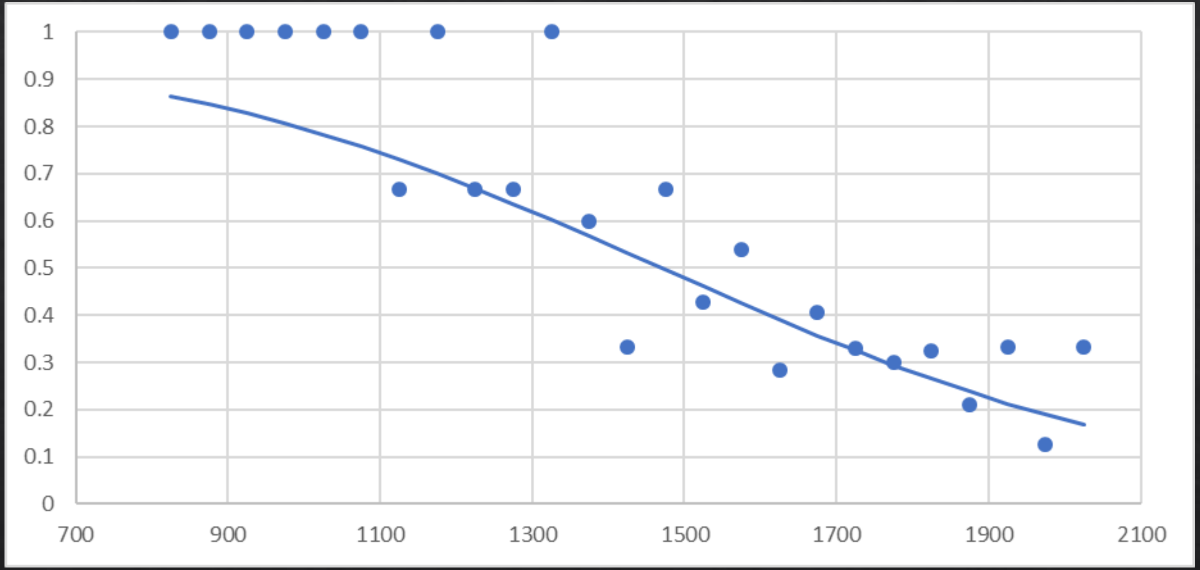
Playback

- Each player and level assigned Glicko-2 ratings (init=1500)
  - Player rating → Skill
  - Level rating → Difficulty
- Compare ratings to compute player's chance of losing level i.e. level difficulty for that player
- Ratings updated based on PvL outcomes
- Each match creates a sample of the game's difficulty curve by recording current player rating and if player won or lost
- Samples grouped into bins by rating and the mean player loss rate for each bin is computed



Survivorship

- In match data, harder levels mostly have matches vs. high skill players
- Only skilled players survive past easy and moderately difficult levels
    - Match up with harder levels in the game
        - Harder levels end up with low ratings



Solution: Phantom Matches

- We create a *phantom match* for each PvL pairing that did not actually occur during gameplay

- For each such pairing between player P and level L, to determine result of phantom match:
  - We note the lowest rated player X that beat level L
  - If P's final rating >= X's rating, then P wins
  - Else P loses

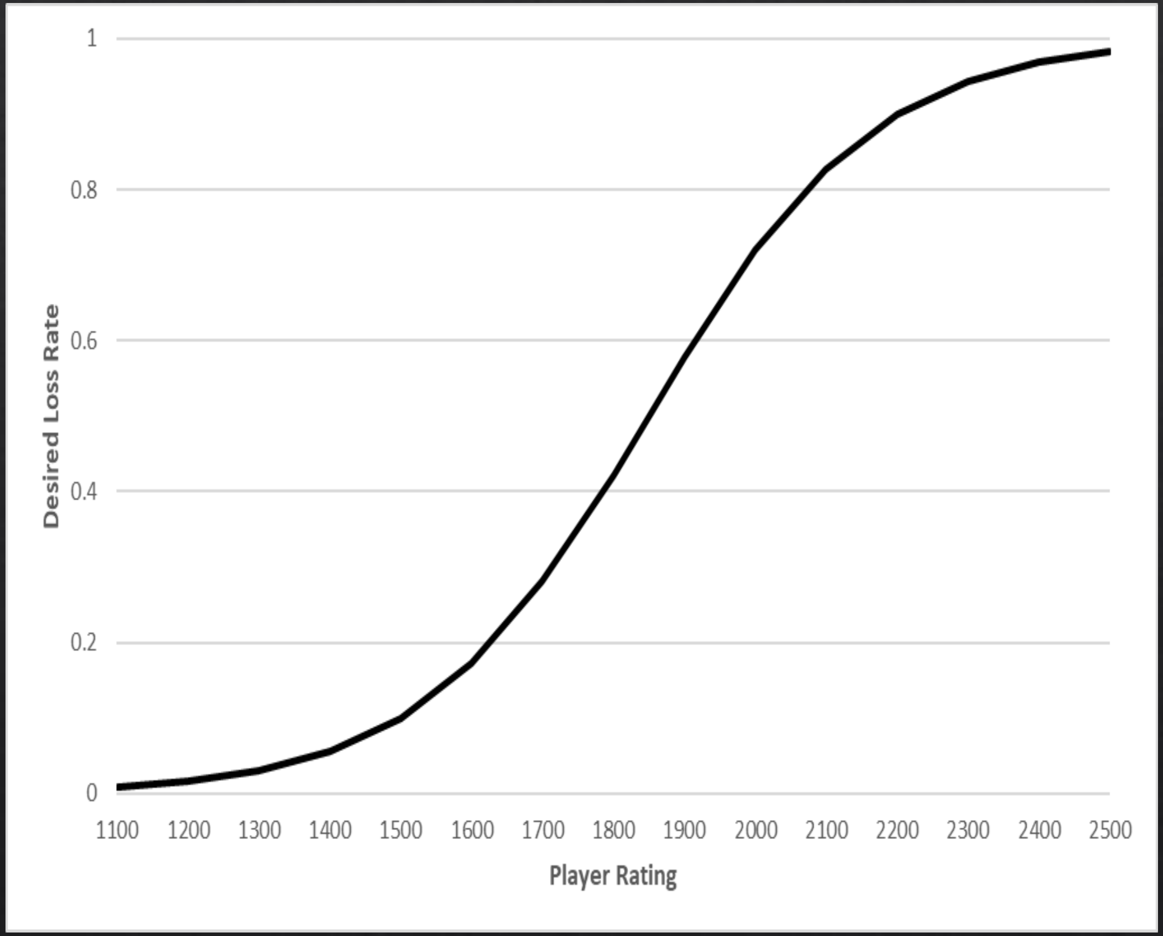
- Phantom matches let harder levels get back wins against low skill players who dropped out

- Combined match data = Real matches + Phantom matches

Fitting Curves to Sampled Data

- To fit a curve to the data, we used a logistic function mapping player rating to loss rate
- Player's loss rate measures difficulty as it determines how hard the next match will be
- Curve taken from prior work in Paradox:

$$f(x) = \frac{1}{1+e^{\alpha(\beta - x)}}$$

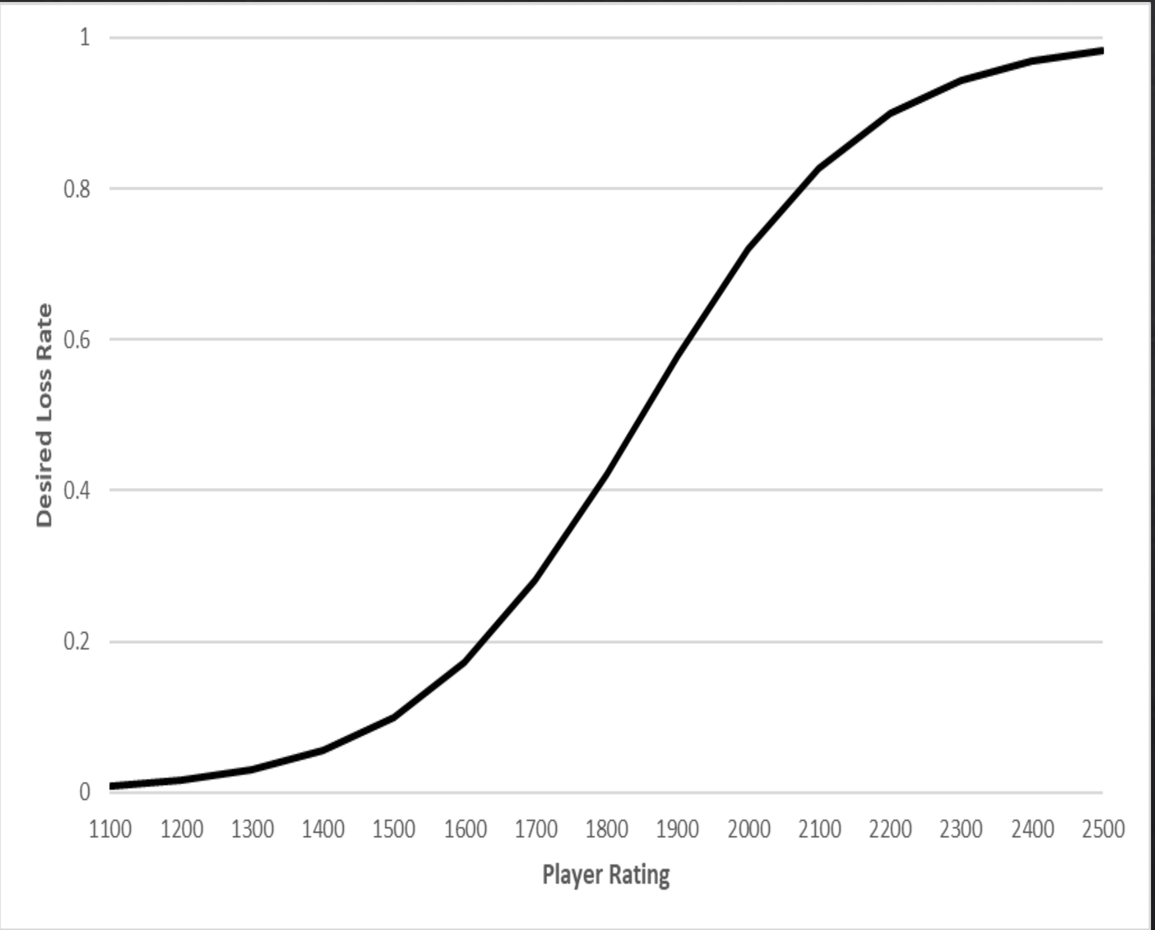


Function Composition

Baseline Curve	Description
$f(x) = \frac{1}{1+e^{\alpha(\beta-x)}}$	Logistic curve

Transformation Functions	Description
$t_\delta(x) = x + \delta$	Translate by δ
$s_{\sigma,c}(x) = \sigma(x - c) + c$	Scale by σ around c

Curve Name	Function	Description
BASELINE	f	baseline curve
INFLATE	$f \circ t_{r_d}$	inflate difficulty via shifting curve left by a constant
DEFLATE	$f \circ t_{-r_d}$	deflate difficulty via shifting curve right by a constant
STEEPEN	$f \circ s_{2,r_l}$	steepen difficulty by increasing curve's rate of change
SMOOTH	$f \circ s_{0.5,r_l}$	smooth difficulty by decreasing curve rate's rate of change



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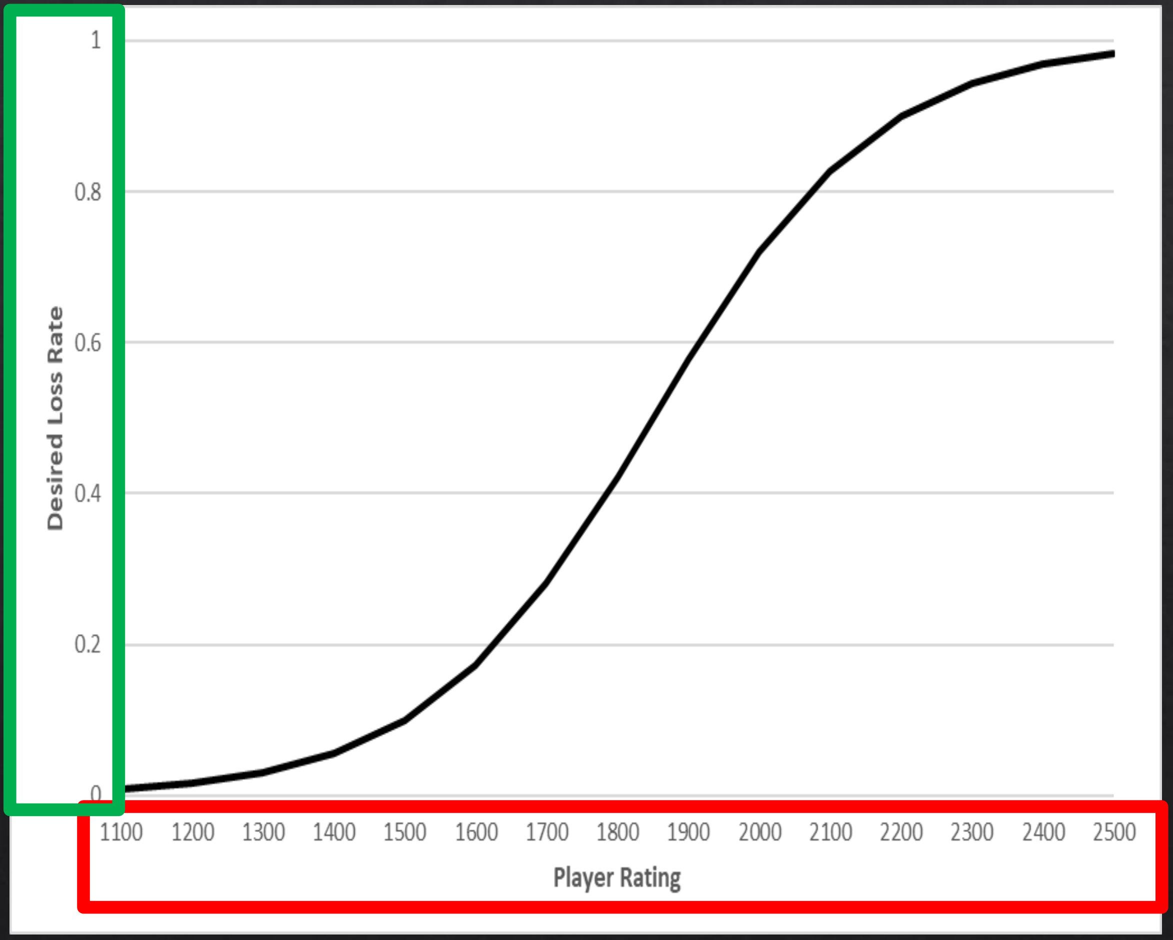

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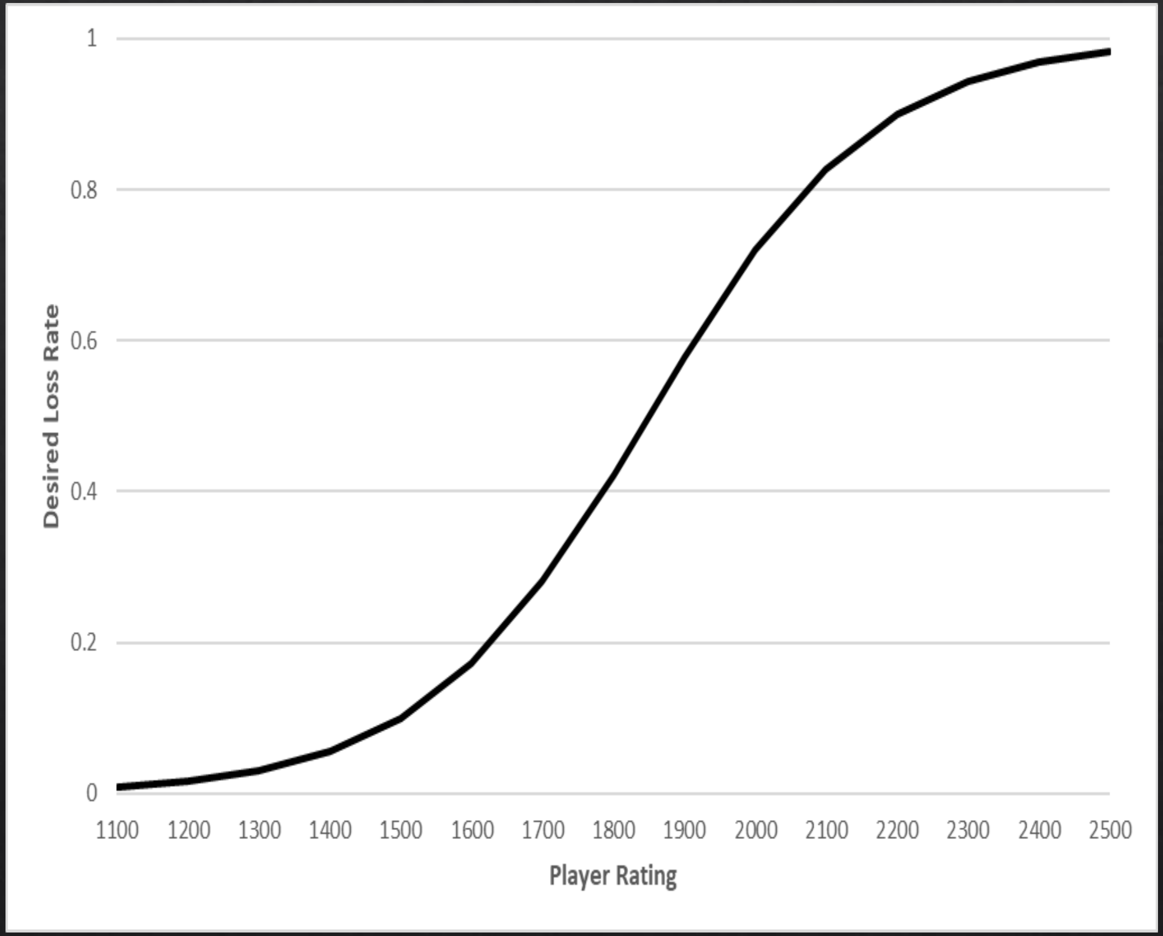

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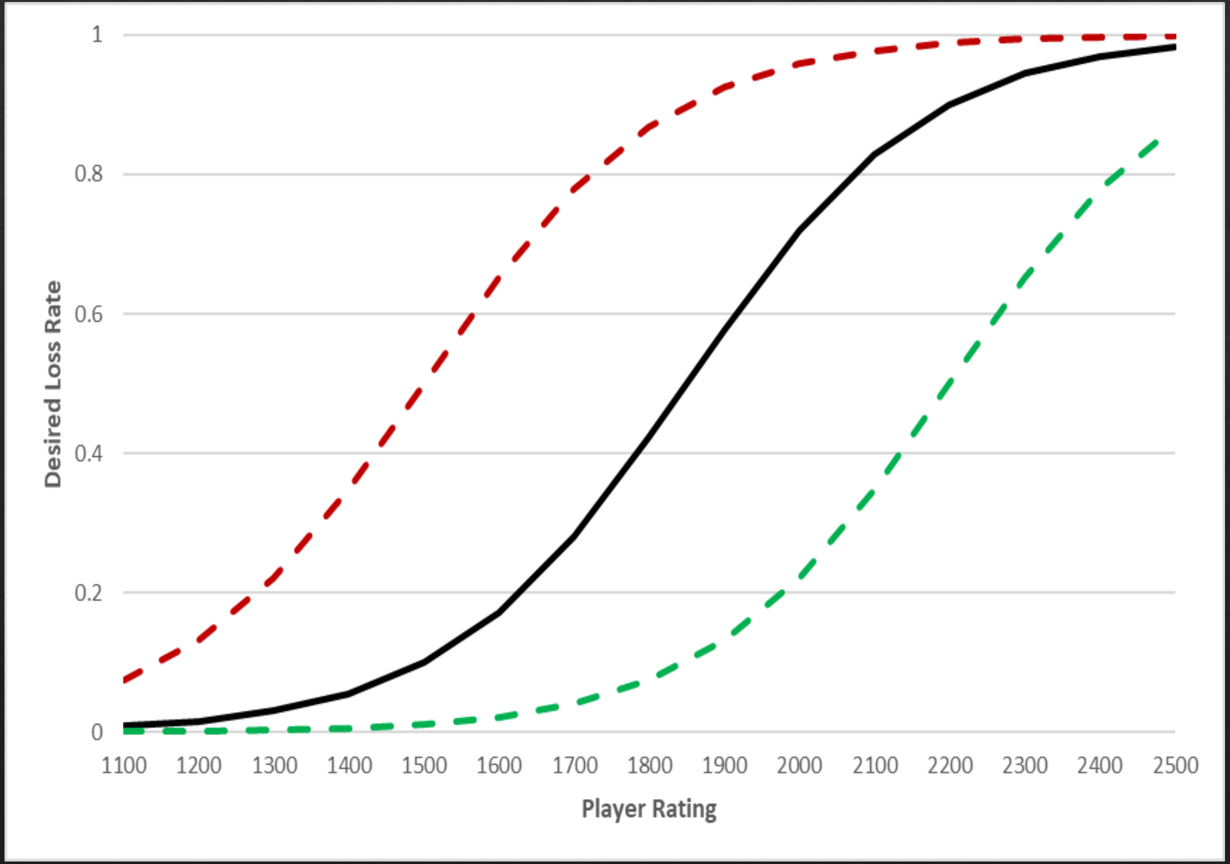

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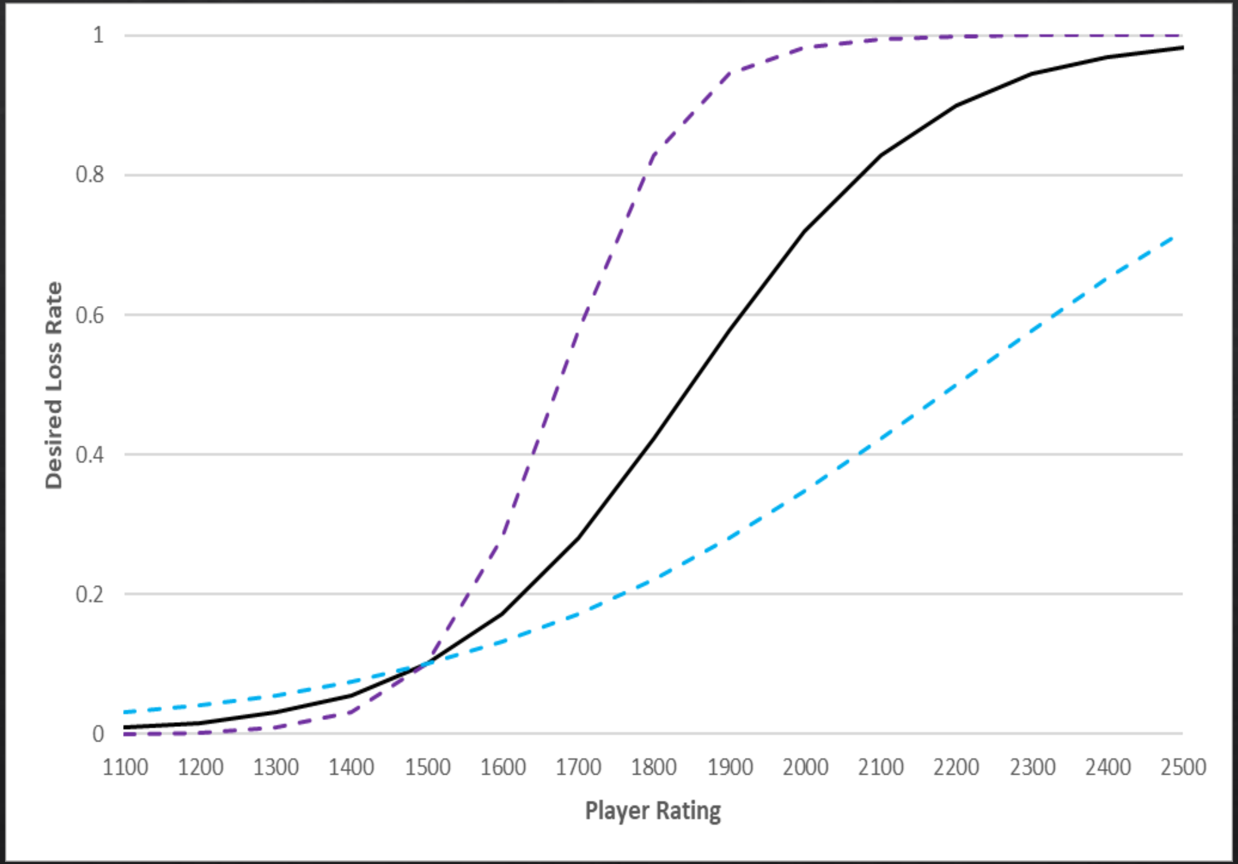

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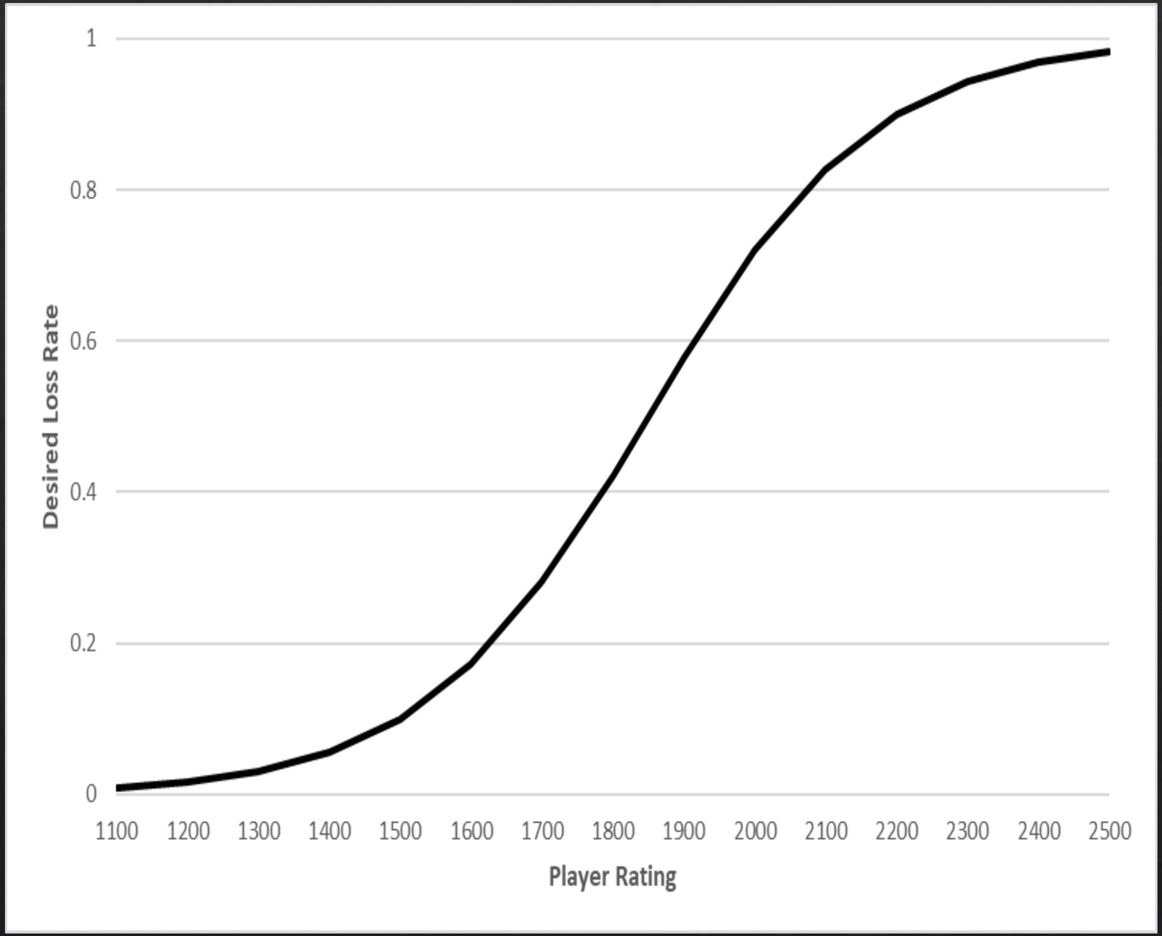
- By composing functions as $f \circ s_{\sigma,c} \circ t_\delta$, we get curves parameterized by δ and σ
- Fit curves to data by optimizing δ and σ to minimize RMSE between curve value at bin centers and mean player loss rate

Phantom Match Validation

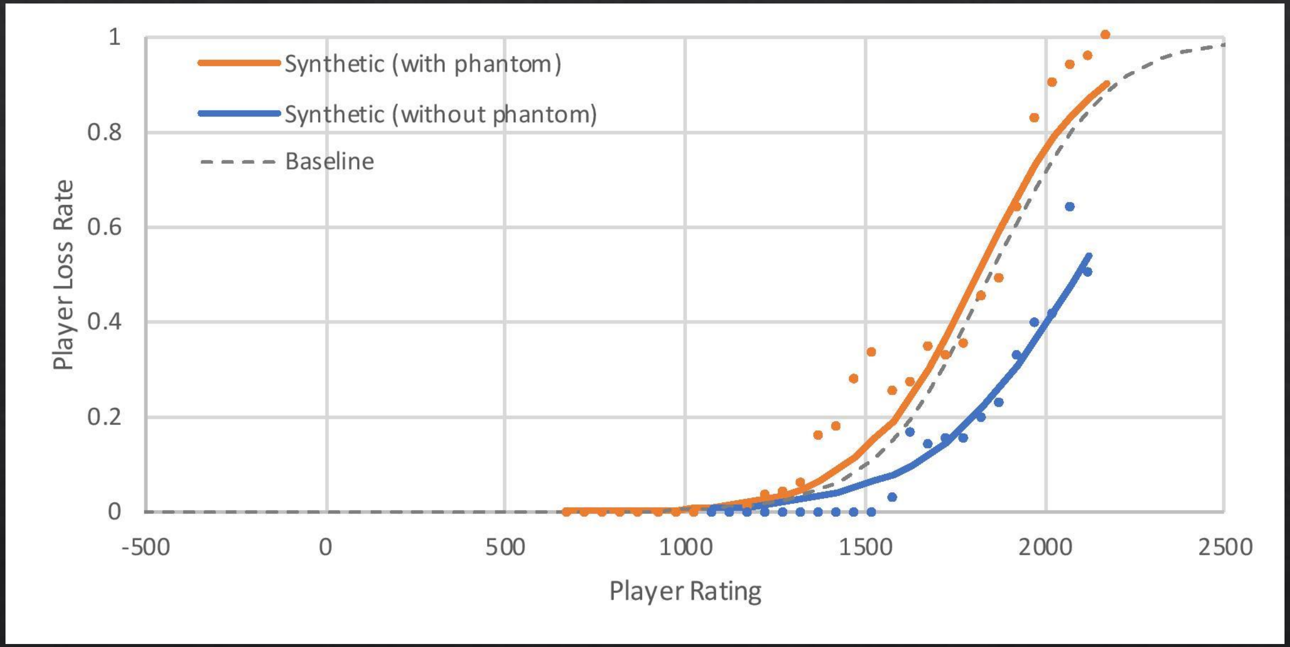
- For validation, we used
  - Synthetically generated dataset
  - Dataset from past trials using *Paradox*

- In both cases, we know the underlying baseline difficulty curve ($\delta = 0$, $\sigma = 1$)



Synthetic Data

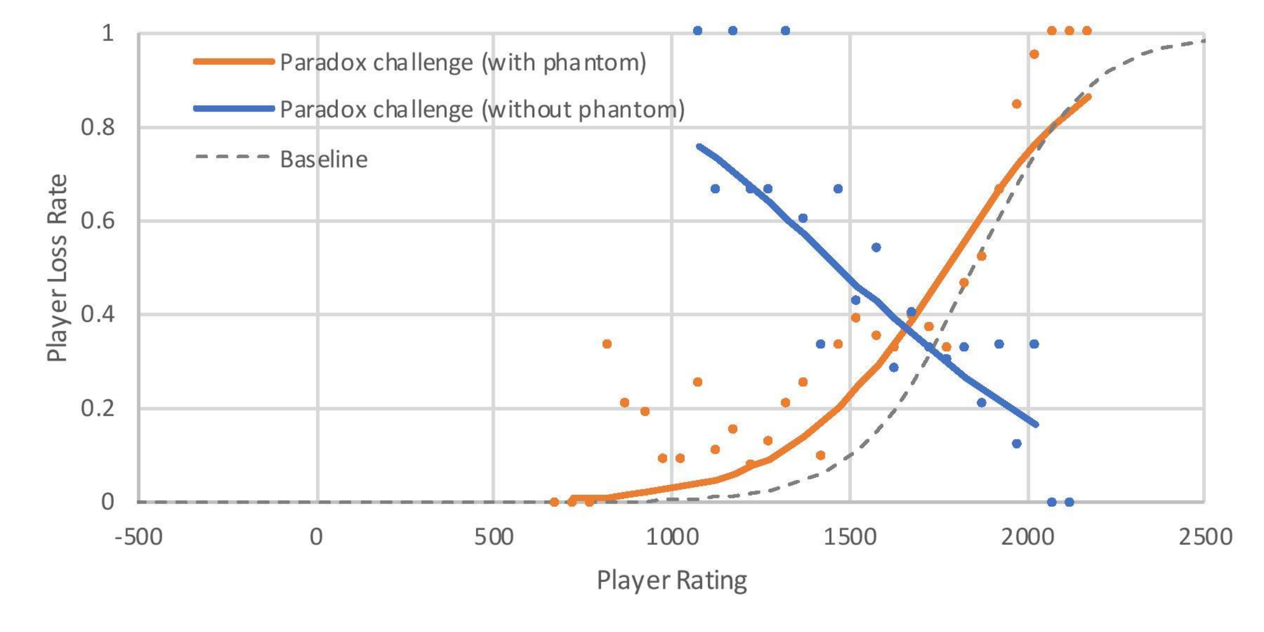
- 50 generated players rated randomly from 900 to 2100
- 61 generated levels rated from 0 to 3000 in increments of 50
- To generate synthetic data
  - Randomly select player
  - Determine best level to serve
  - Simulate match result using the rating system
  - If player loses, stops playing via a drop rate
  - Continue simulation until no players remain



Paradox

- Gameplay data from challenge portion of *Paradox* gathered from prior work

- Used baseline curve to perform DDA, so applying phantom matches should help recover this curve



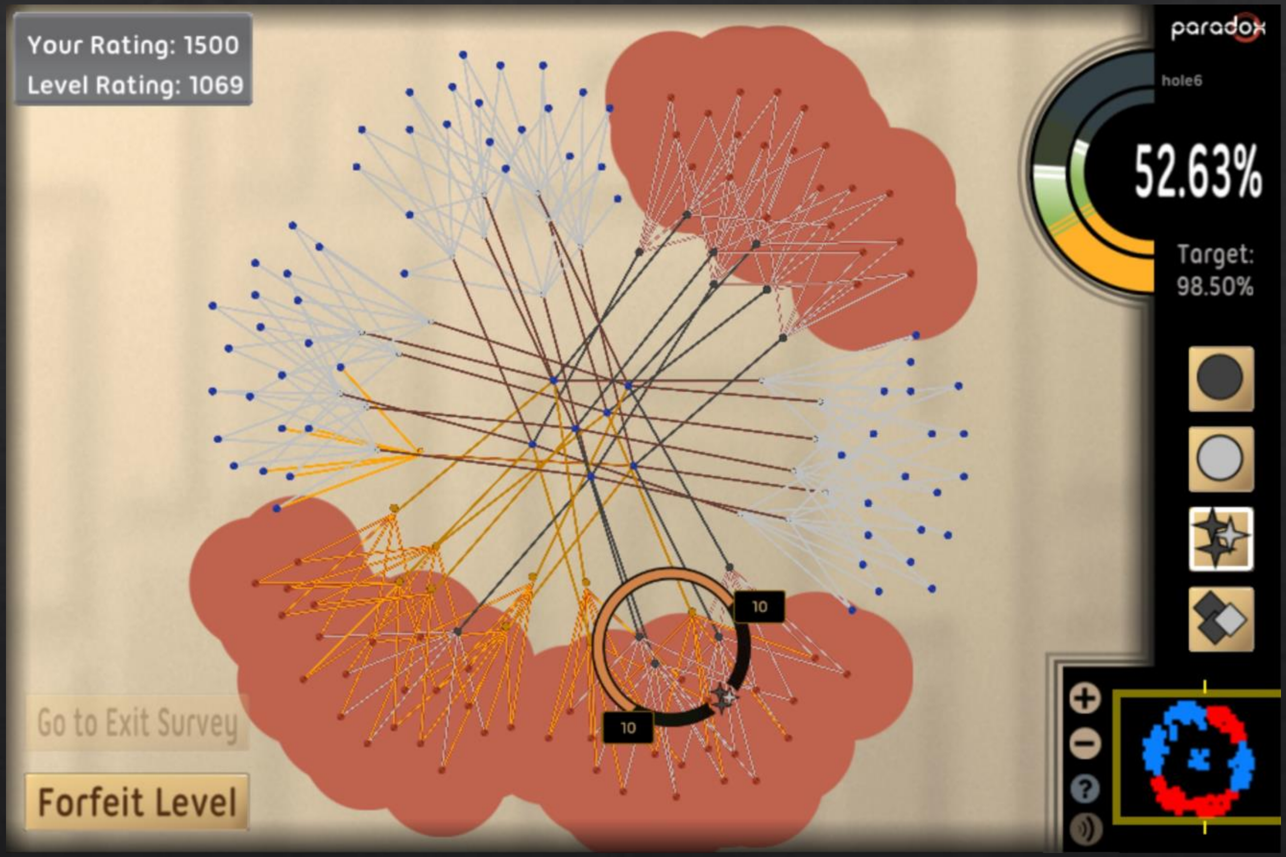
Games

- Used gameplay data from 4 games to apply our approach
  - *Paradox*
  - *Iowa James*
  - *Signaligner*
  - *Foldit*

- Existing dataset for first three gathered through Amazon Mechanical Turk
- Existing *Foldit* data gathered through website https://fold.it

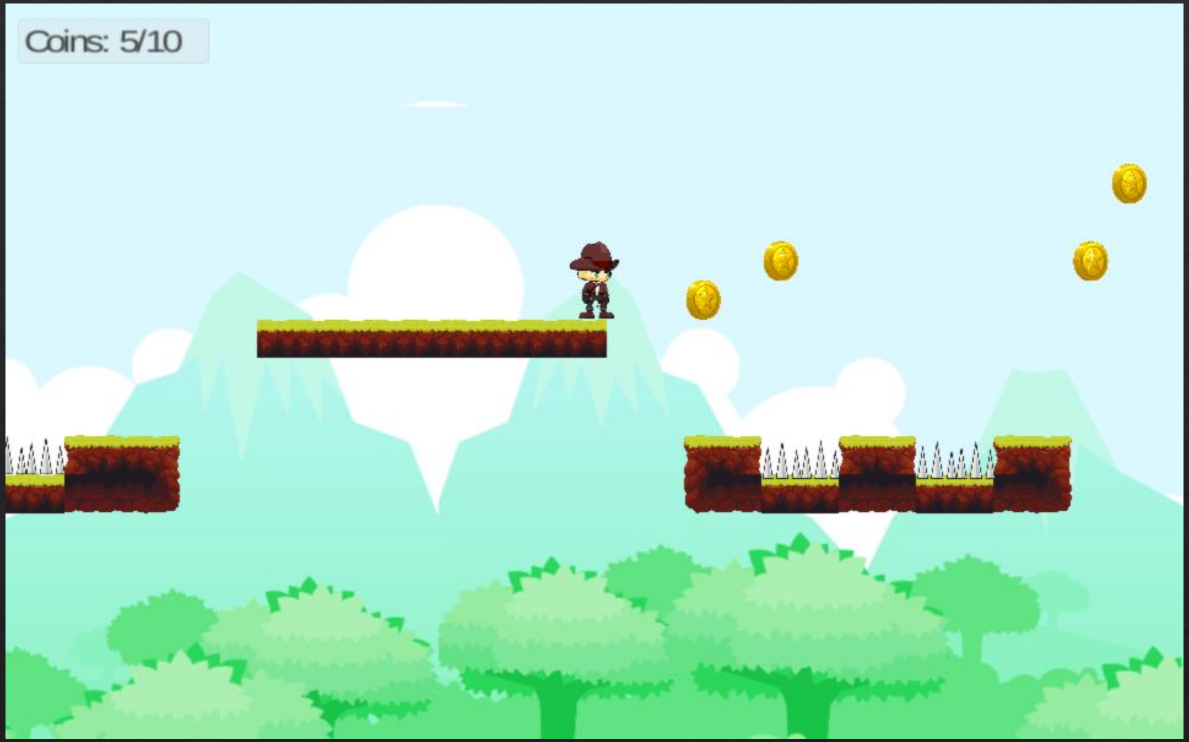
Paradox

- 2D human computation puzzle game
- Each level is a MAX-SAT problem with a target number of constraints to be satisfied
- Players assign values to variables to solve constraints
- Score: percentage of satisfied constraints
- Goal: complete level by reaching target score
- Player wins vs. a level by completing it
- 8 tutorial levels → fixed order
- 50 challenge levels → dynamic order



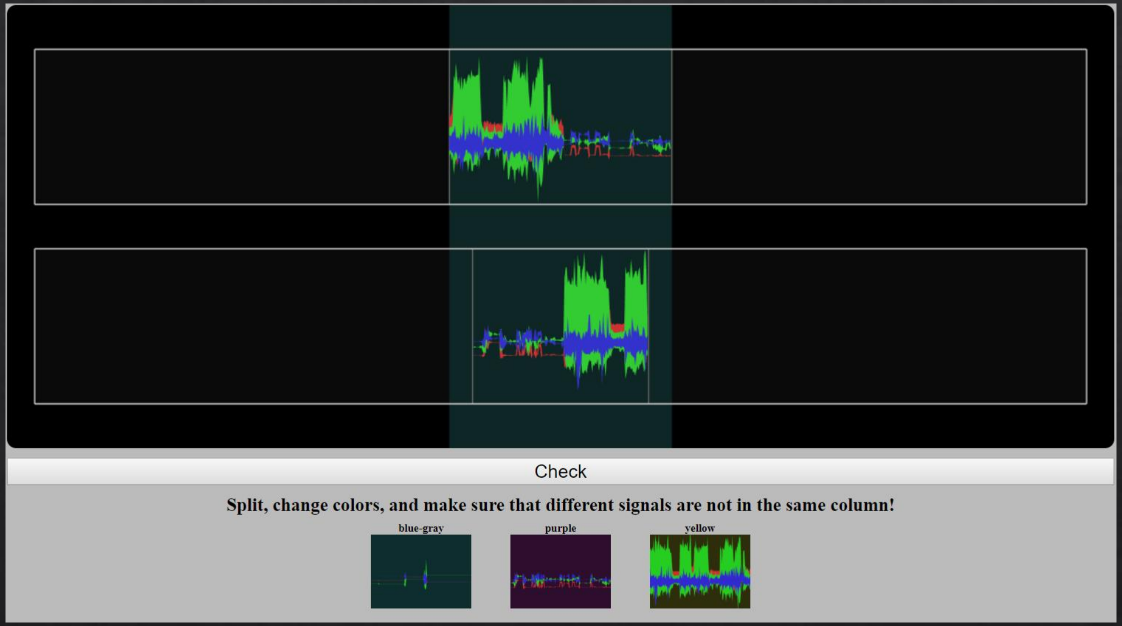
Iowa James

- Basic platformer with 14 levels following an increasing difficulty ordering
- Each level has hazards that player must avoid
- Goal: reach treasure chest at the end of the level
- Player wins vs. a level by reaching the chest, regardless of number of deaths
- Player loses by quitting the level without reaching the chest



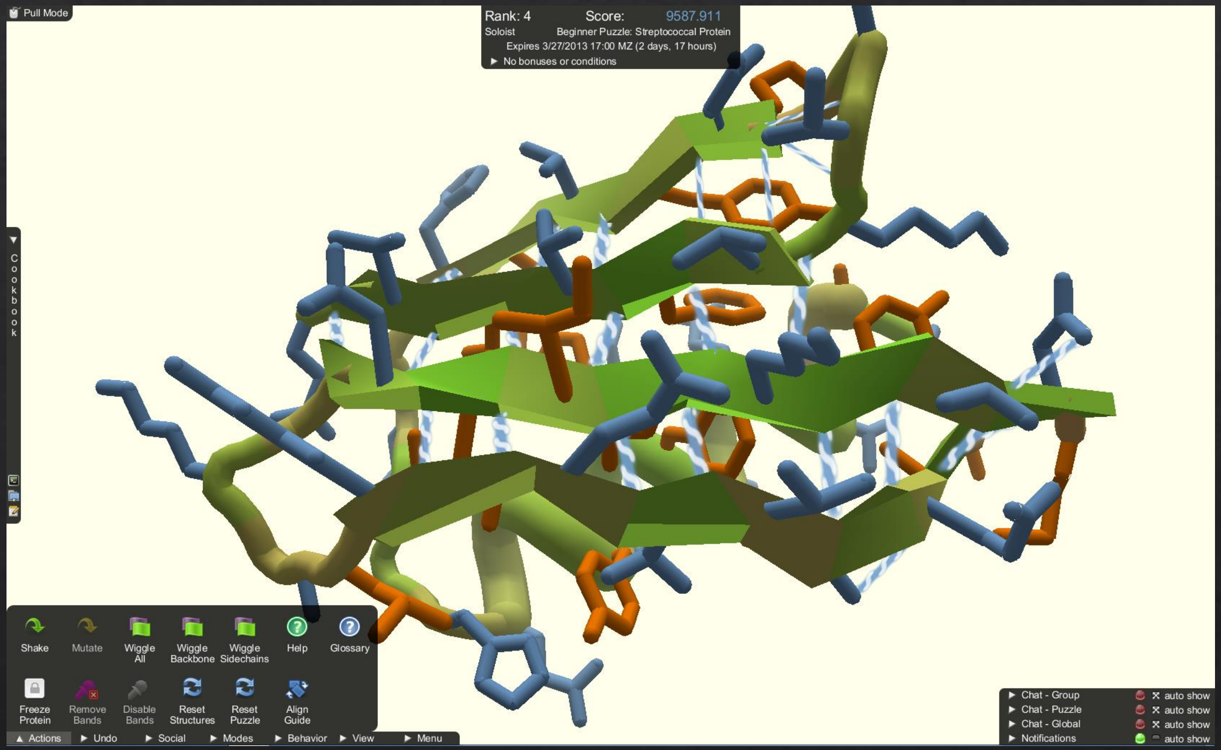
Signaligner

- 2D human computation puzzle game
- Players annotate raw accelerometer data with activity labels
- Group together similar looking data signal blocks by splitting, merging or aligning
- 4 tutorial levels and 1 of 7 possible challenge levels
  - Tutorial → multiple attempts to submit correct answer
  - Challenge → one attempt; players win if they submit correct answer



Foldit

- Human computation puzzle game based on protein folding
- Players interactively fold and pack protein structures
- 37 tutorial levels were used for this analysis
- Score: energy of the current fold
- Players win a level by reaching the target score
- Tutorial progression is same for all players but players have choices at branching points and can replay previous levels

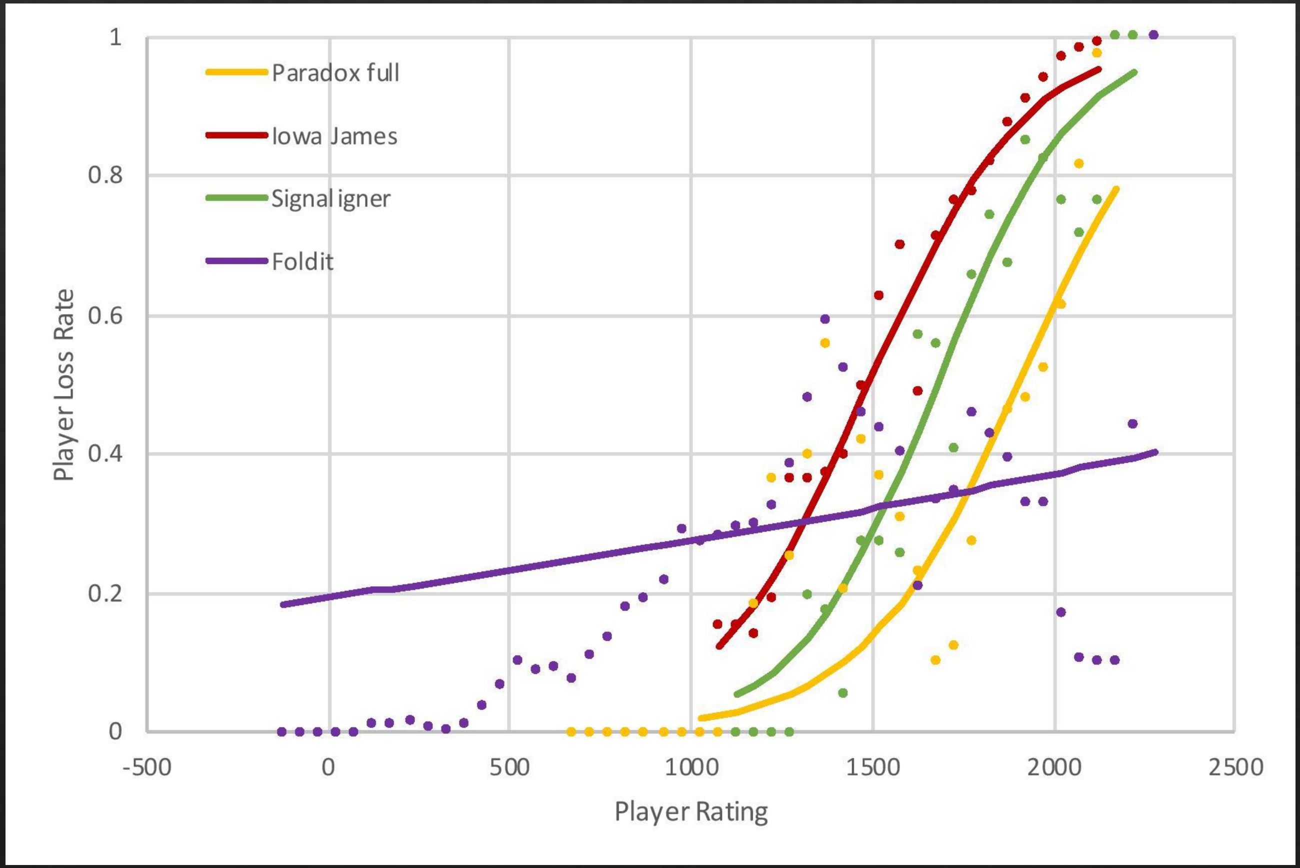


Curve Comparisons and Transformations

- Using our approach we fit difficulty curves on data for all 4 games

- Function composition-based terminology
  - *Foldit* has the smoothest curve
  - Other 3 games have steeper curves
  - Of these 3, *Iowa James* has an inflated curve compared to *Signaligner* and *Paradox*
  - *Paradox* has the most deflated curve

- *Paradox* and *Foldit* curves have the highest error
  - Single curve does not fit data well and multiple curves may be needed



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