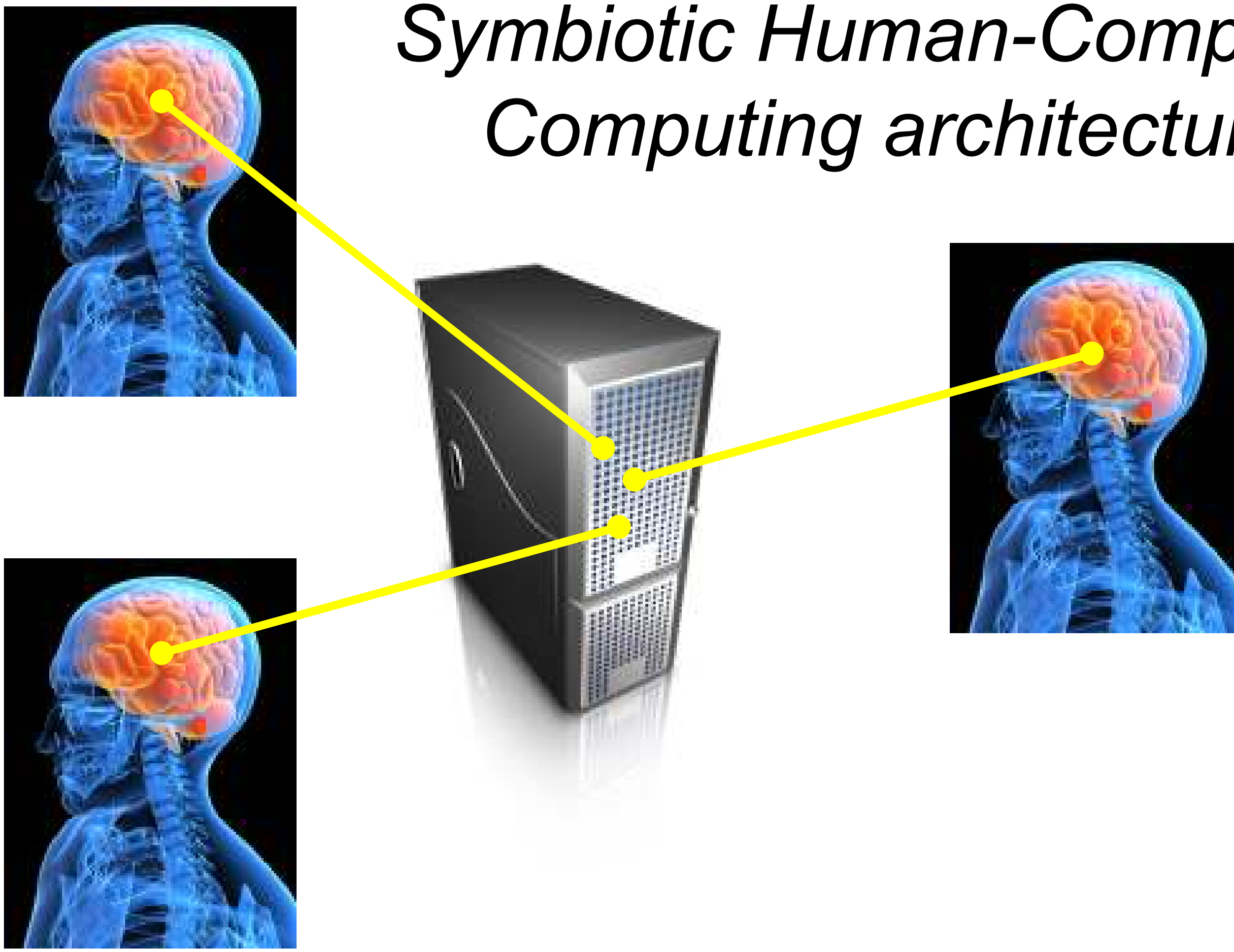
Center for Game Science

- Over 35 PhD, ugrads, SDEs, desginers, artists
- 6 games currently in development

Symbiotic Human-Computer Computing architecture



Solving Hard Problems with Human-Computer Symbiosis

Coadaptation:

1. People → Experts
2. Programs/Games → Optimal problem tools

Games are an ideal vehicle of coadaptation

Center for Game Science

- Over 35 PhD, ugrads, SDEs, desginers, artists
- 6 games currently in development

The Challenge:

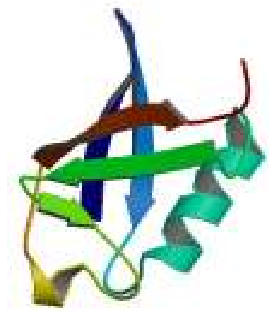
1. hard to make an entertaining game
2. even harder do it and solve a hard problem
   - constraints on game design
   - make real discovery, really learn something
   - Long term involvement

- cannot separate the two objectives
- Very different than standard game design

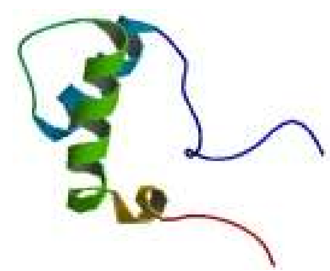
Evidence?

Proteins

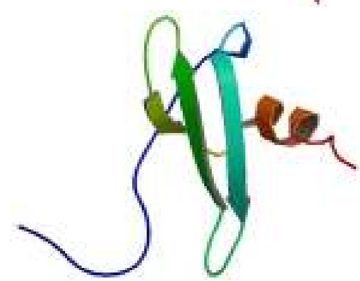
MQIFVKTLTGKTILEVEPSDTIE…



MGKYDKQIDLSTVDLKKLRVKEL…



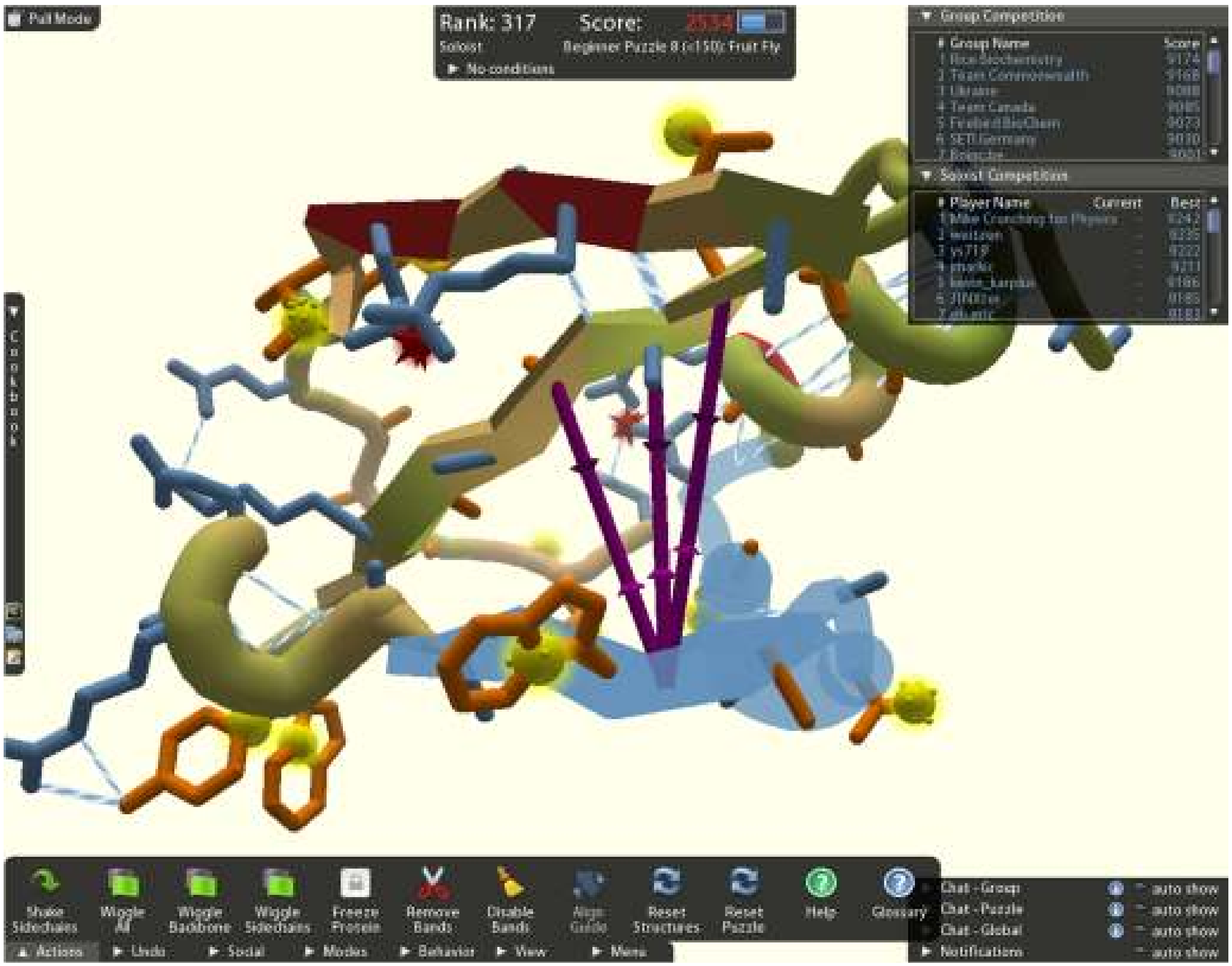
KPVSLSYRCPCRFFESHVARANV…



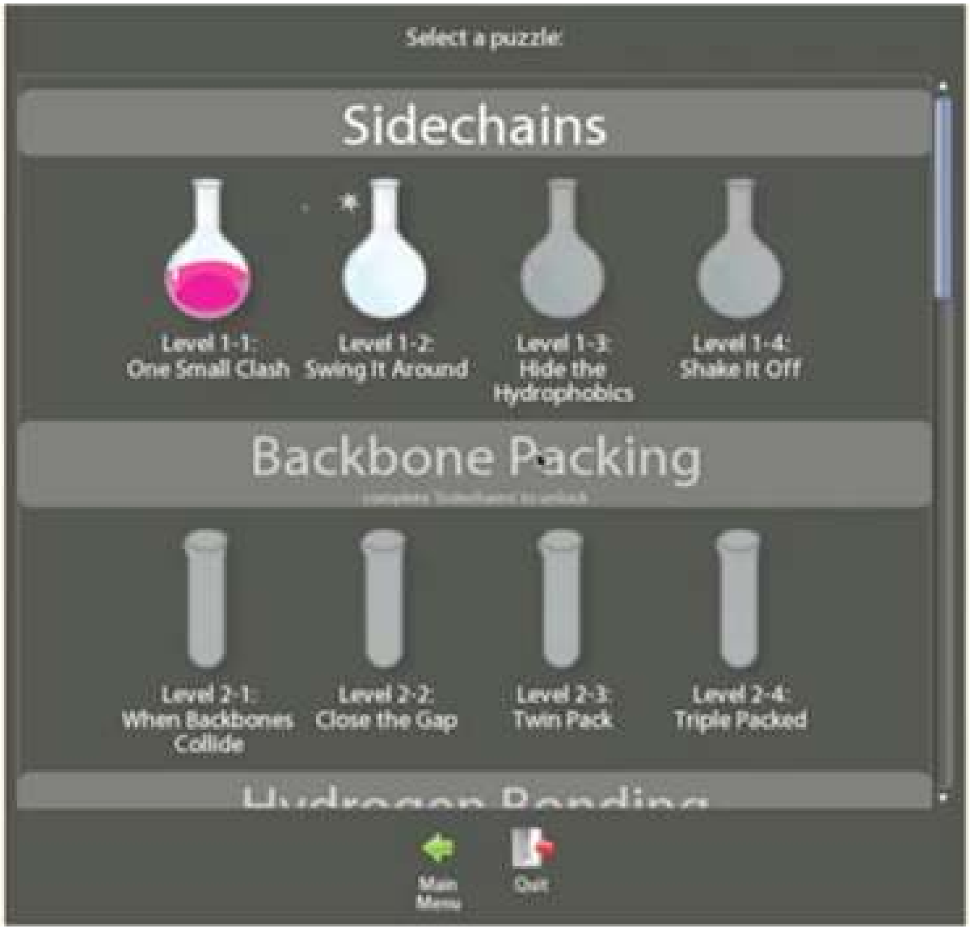
⋮ ⋮

Sequence 3D Structure

Foldit

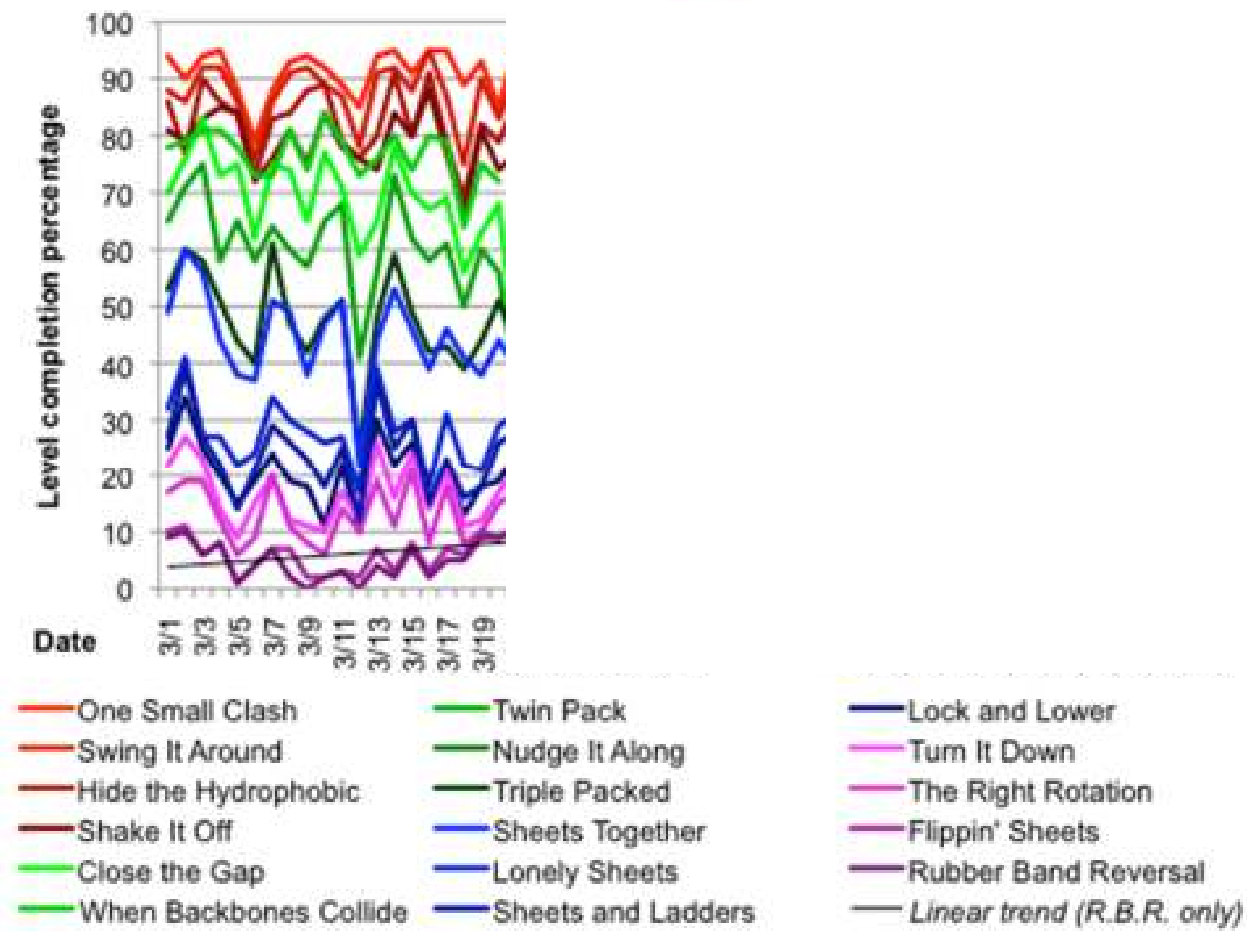

Pull Mode
Rank: 317
Score:
Soloist
Beginner Puzzle 8 (<150): Fruit Fly
No conditions
Group Competition
Group Name
Score
Soloist Competition
Player Name
Current
Best
Shake Sidechains
Wiggle All
Wiggle Backbone
Wiggle Sidechains
Freeze Protein
Remove Bands
Disable Bands
Reset Structures
Reset Puzzle
Help
Glossary
Chat - Group
Chat - Puzzle
Chat - Global
Notifications
auto show
Actions
Undo
Social
Modes
Behavior
View
Menu

Training


Select a puzzle:
Sidechains
Level 1-1: One Small Clash
Level 1-2: Swing It Around
Level 1-3: Hide the Hydrophobics
Level 1-4: Shake It Off
Backbone Packing
Level 2-1: When Backbones Collide
Level 2-2: Close the Gap
Level 2-3: Twin Pack
Level 2-4: Triple Packed
Main Menu
Quit

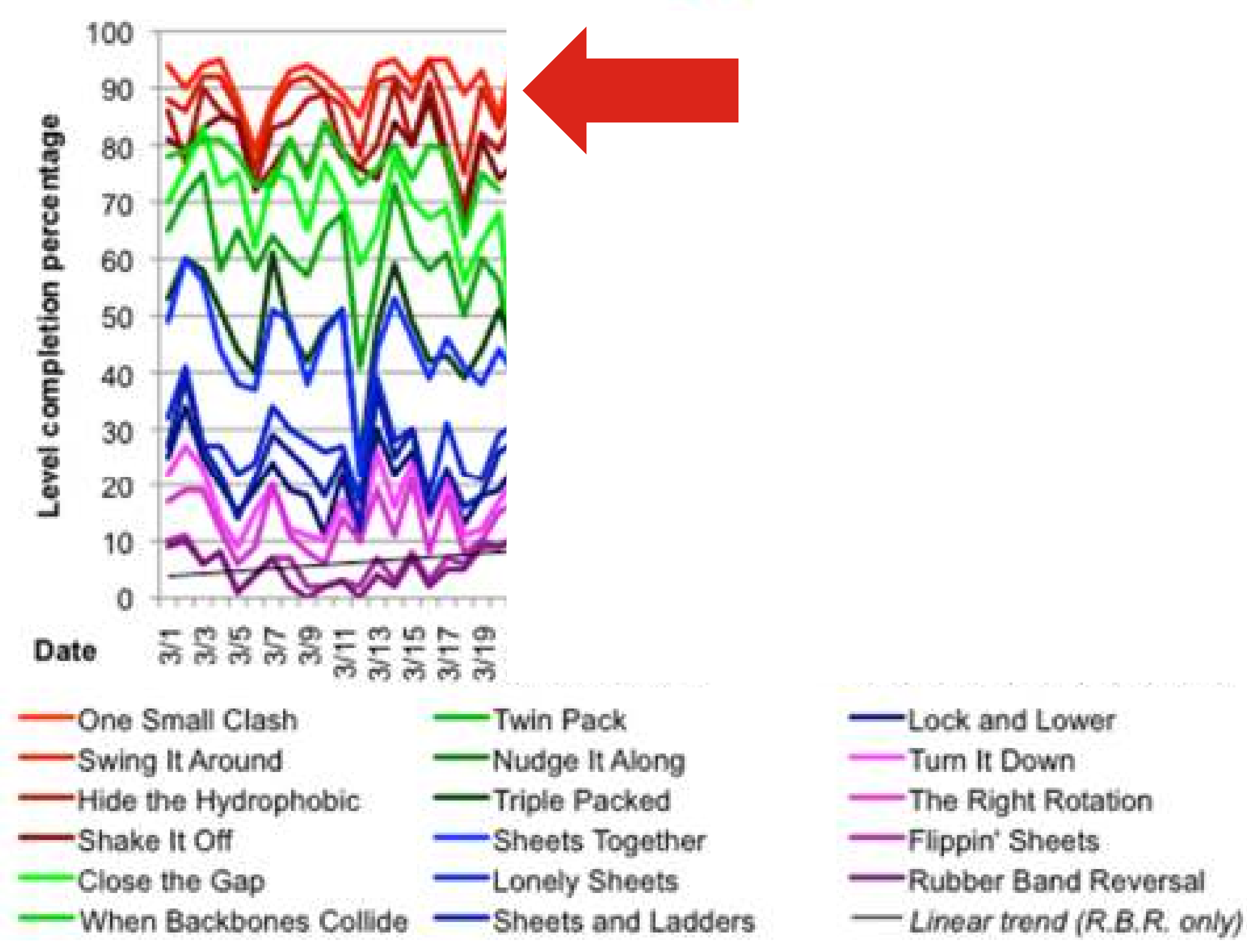
Training

refinement



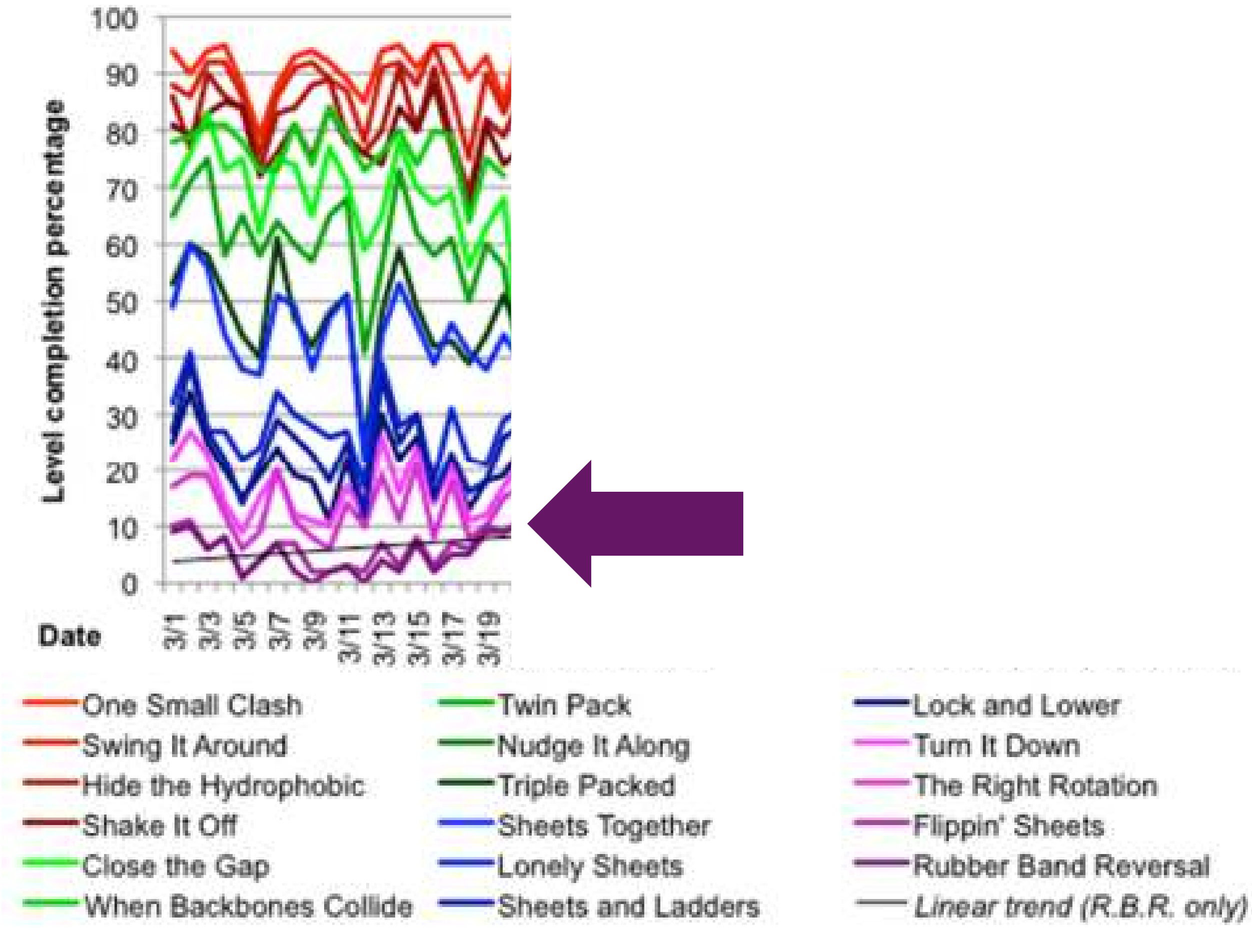
Training

refinement



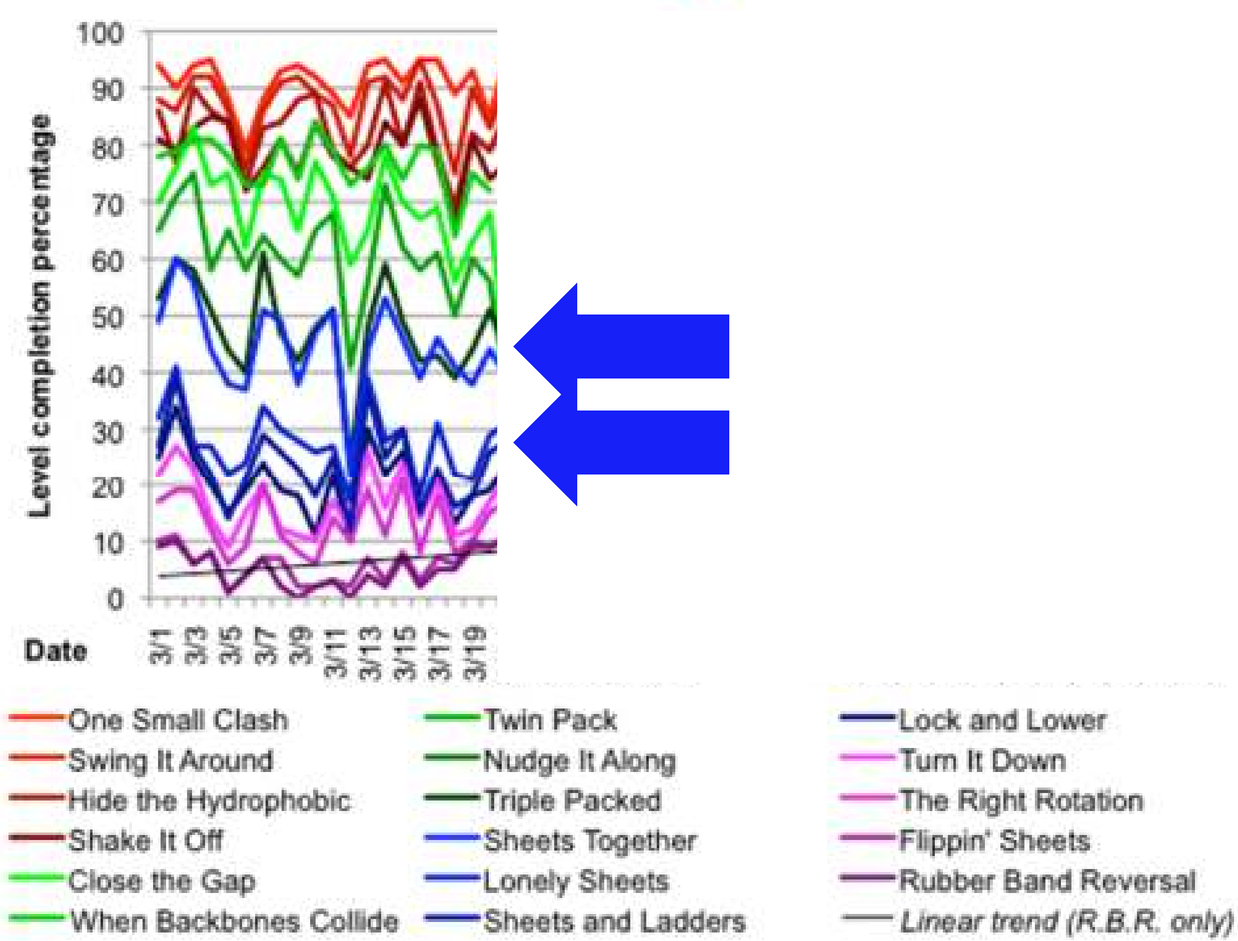
Training

refinement



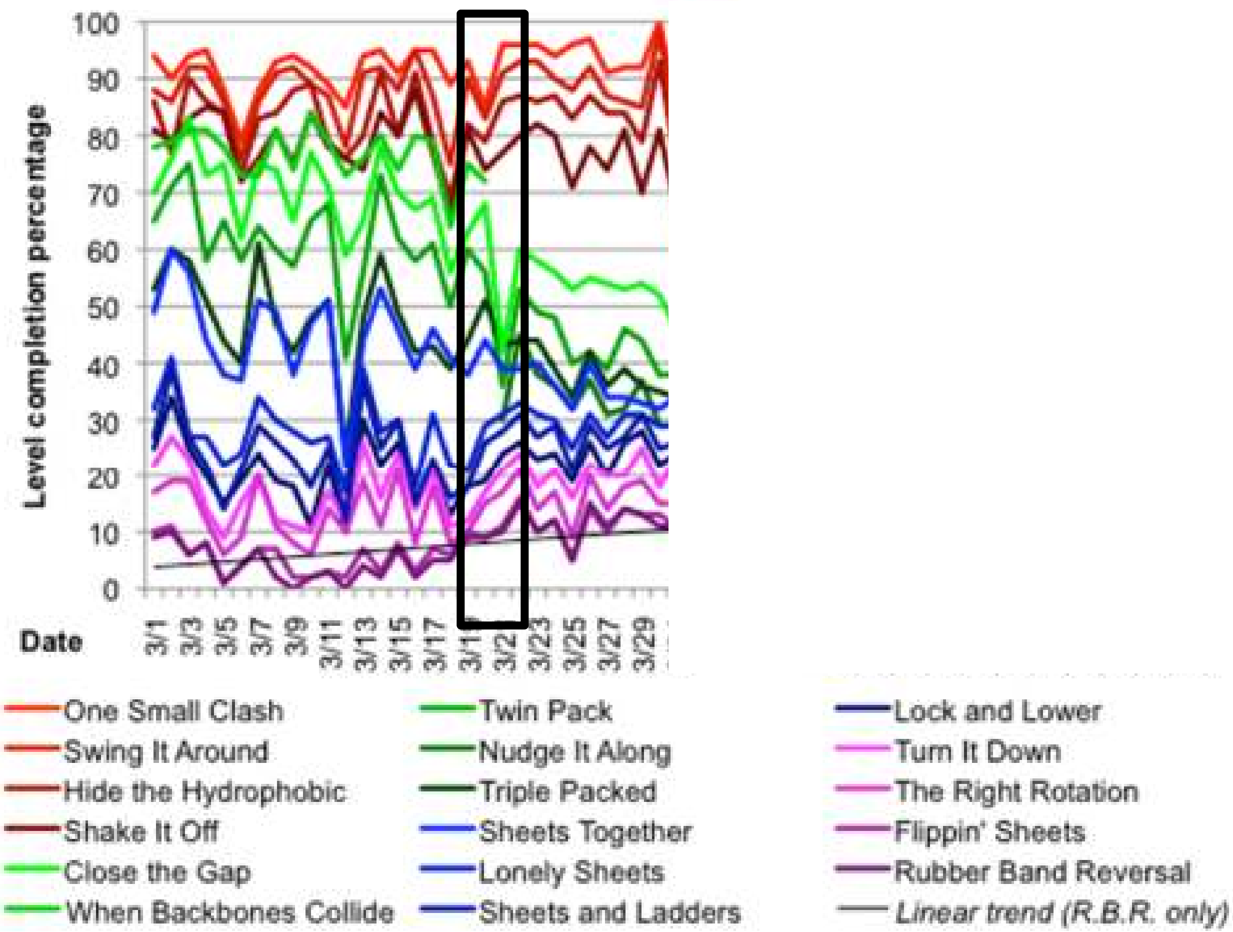
Training

refinement



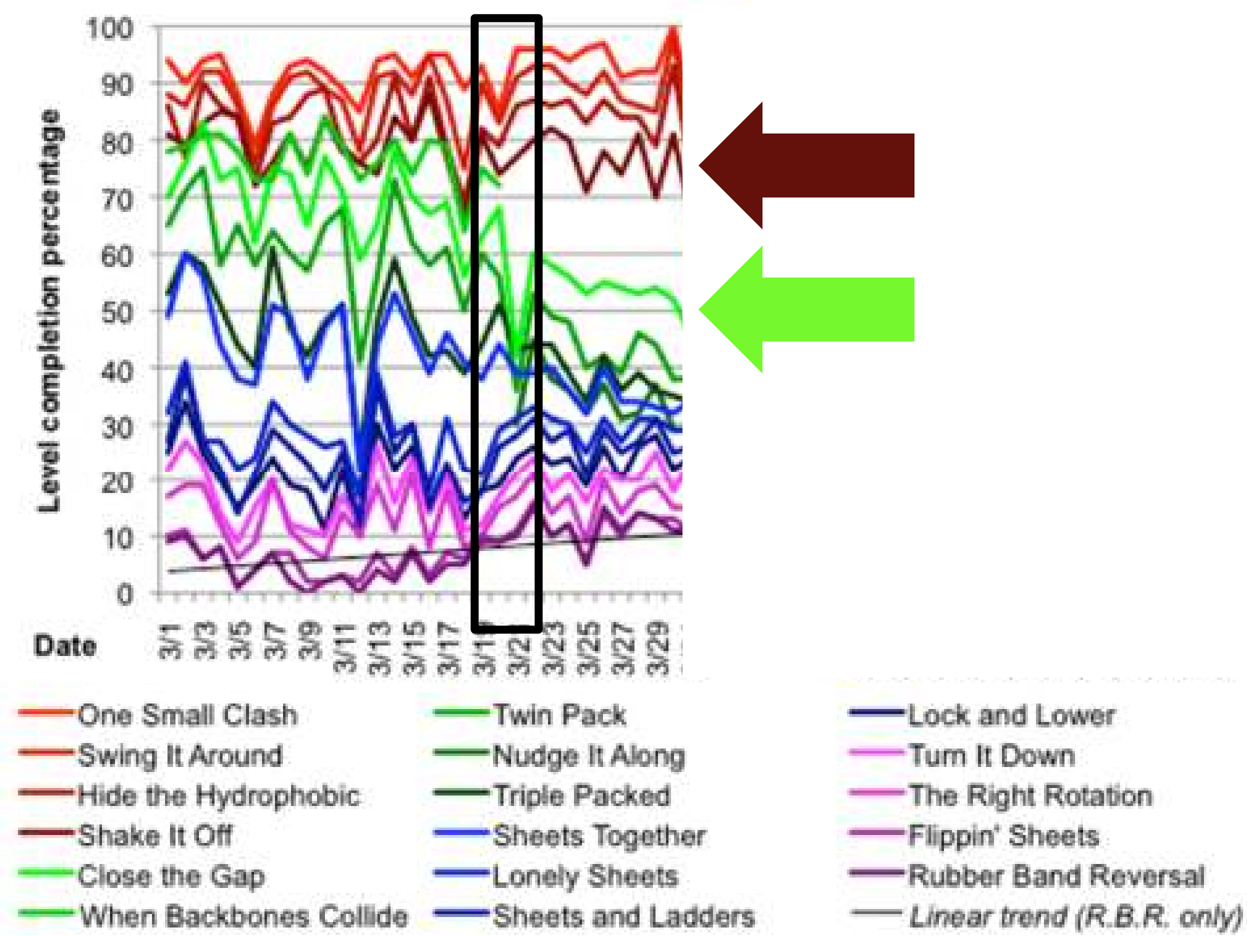
Training

refinement



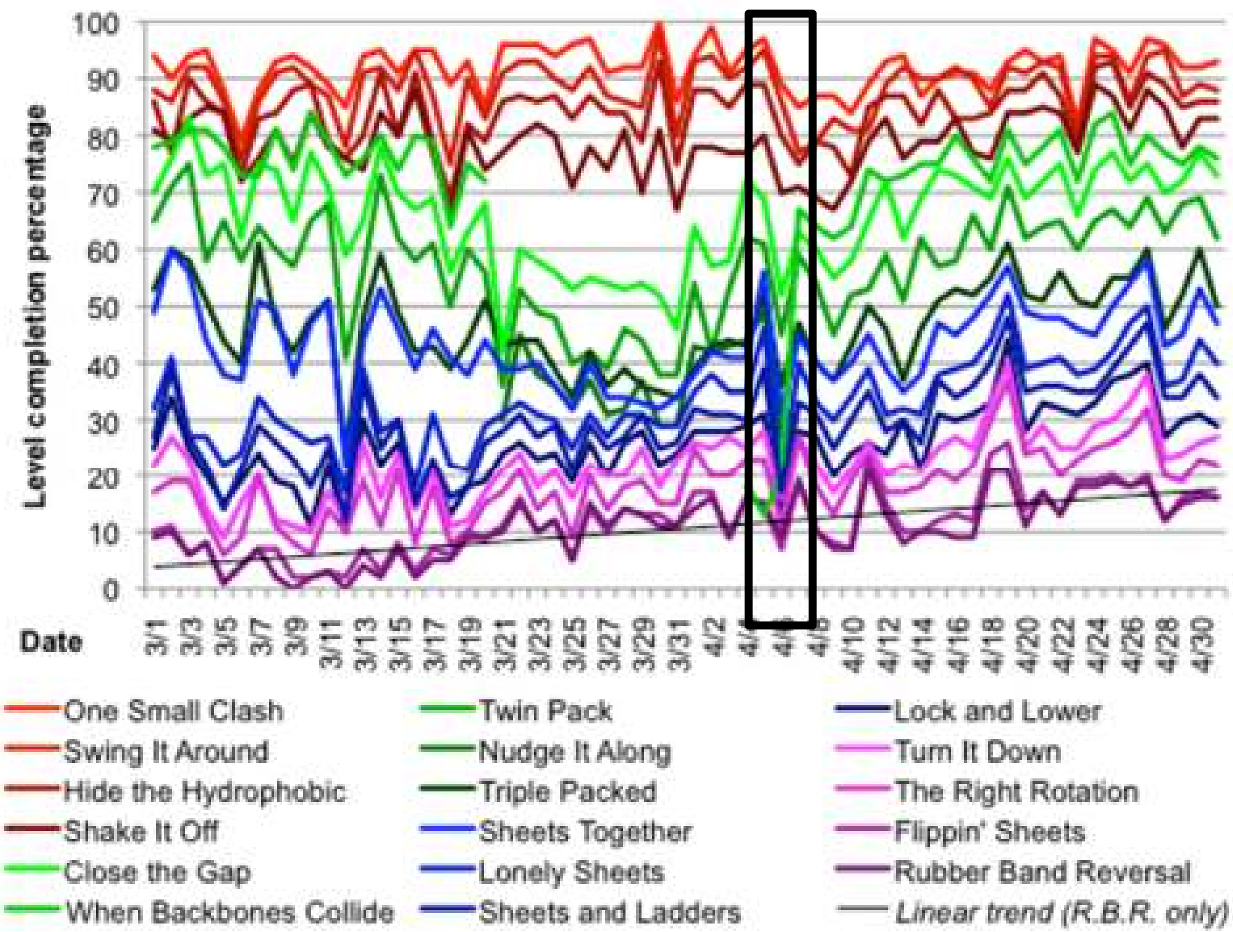
Training

refinement



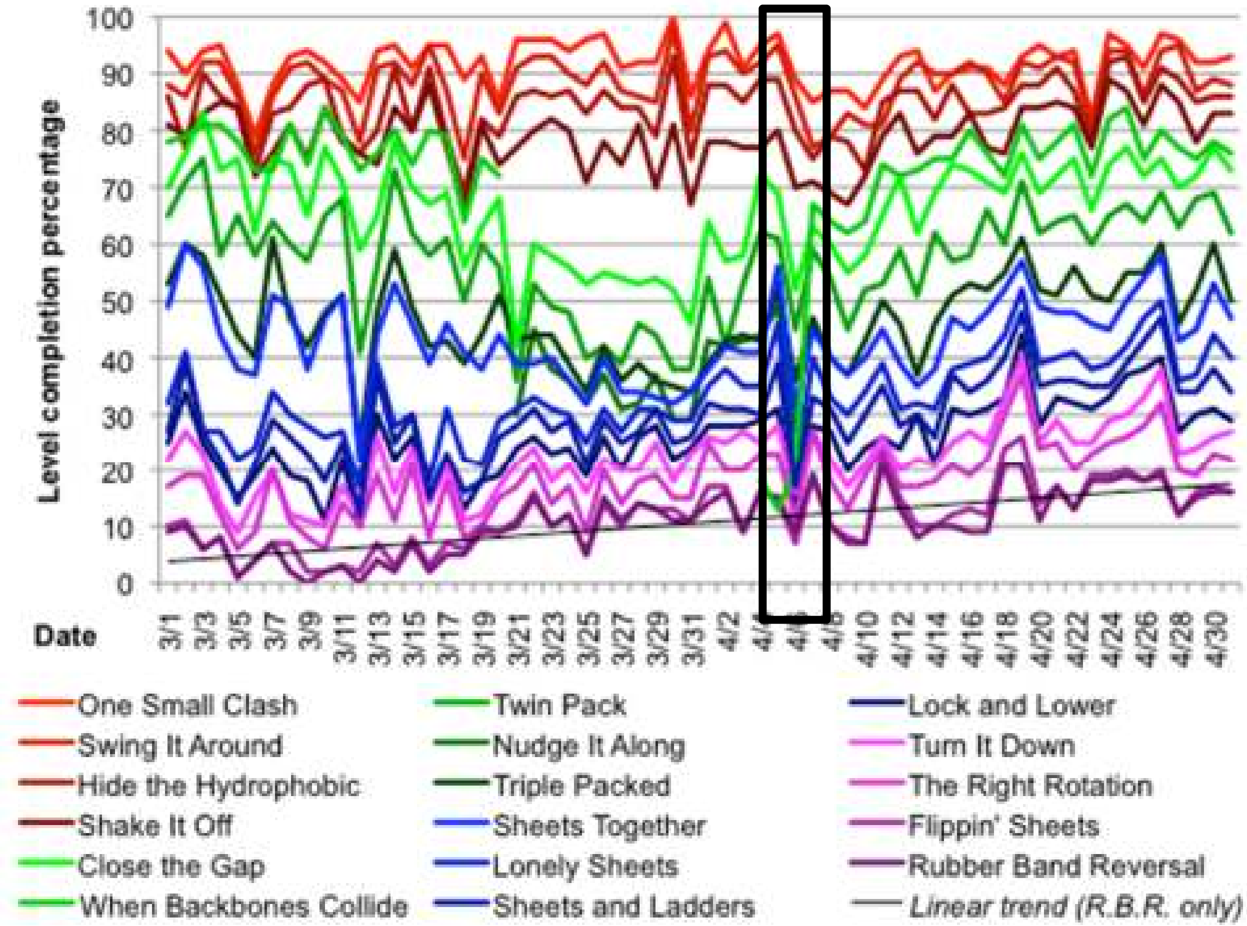
Training

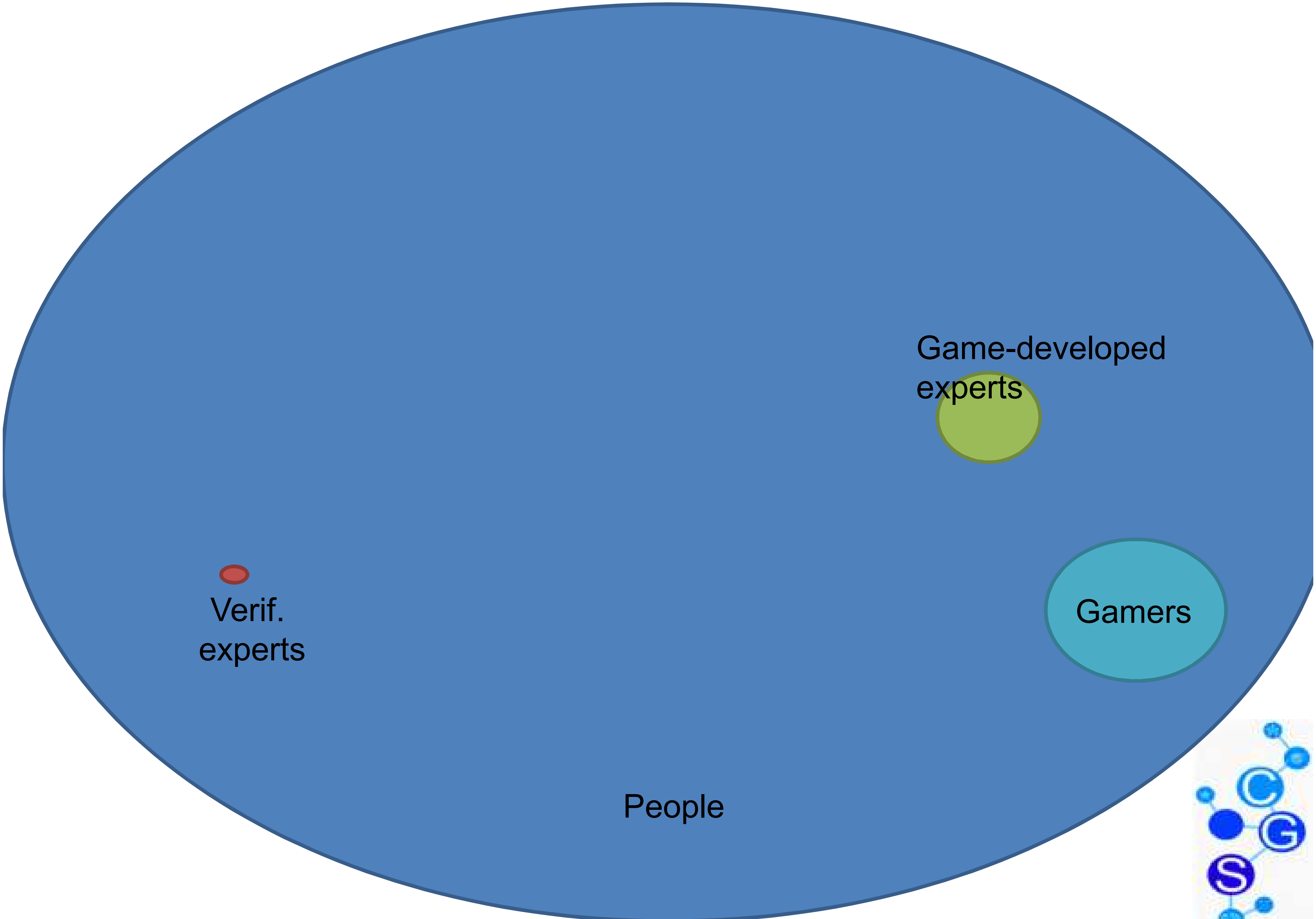
refinement



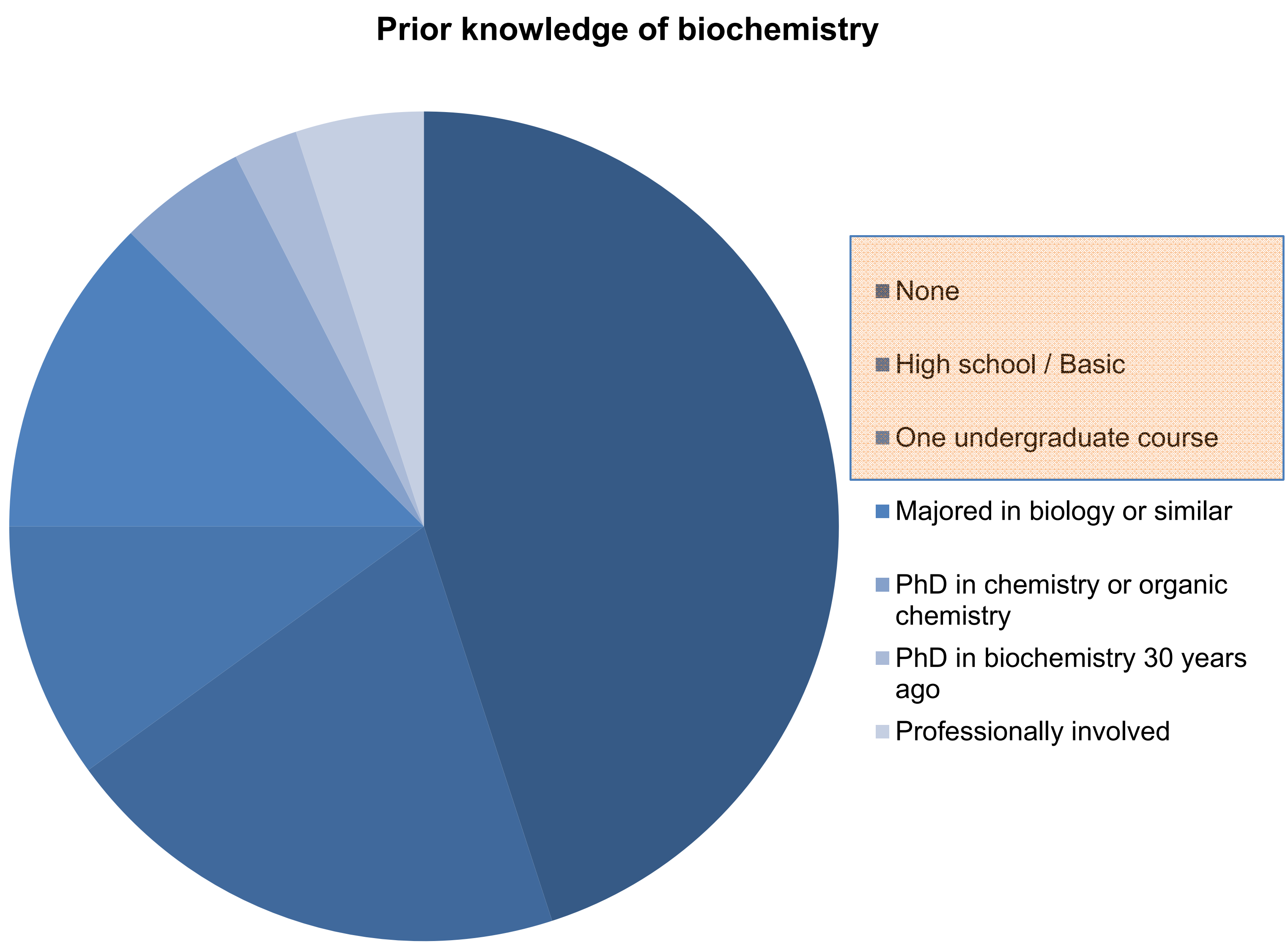
Training

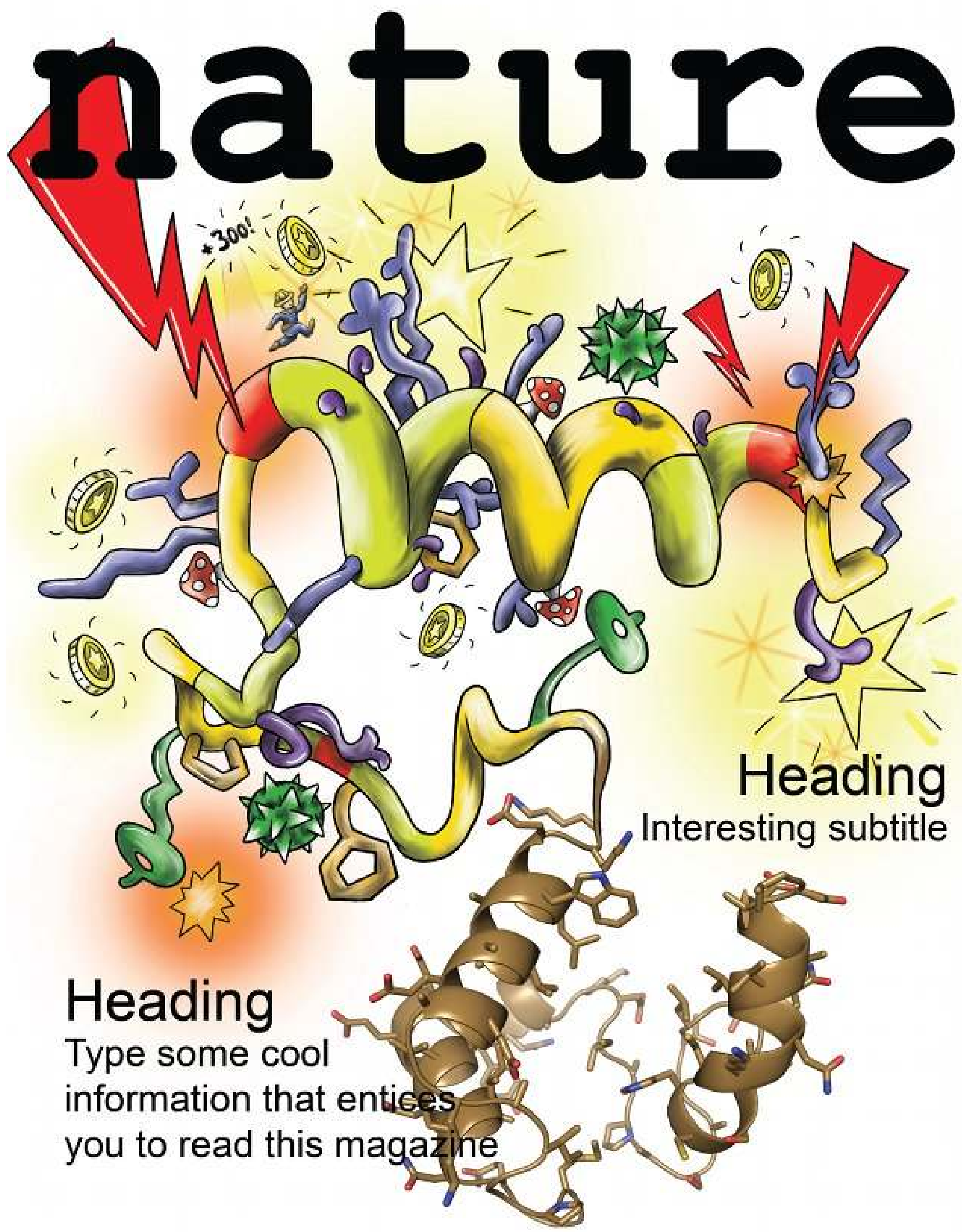
refinement




Game-developed
experts
Verif.
experts
Gamers
People

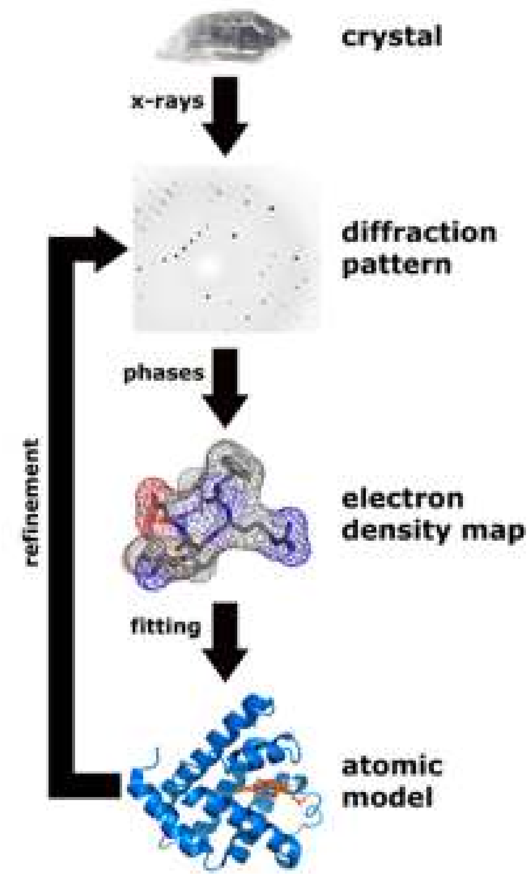
Biochemistry not just for experts…




nature
Heading
Interesting subtitle
Heading
Type some cool
information that entices
you to read this magazine

Experimental Structure Solved

- Mason-Pfizer Monkey Virus Retroviral Protease (MPMV PR)
- Plays a role in AIDS in monkeys
- Experimentalists worked on for ~15 years
- Computational methods failed to solve
- Gave to players for 3 weeks

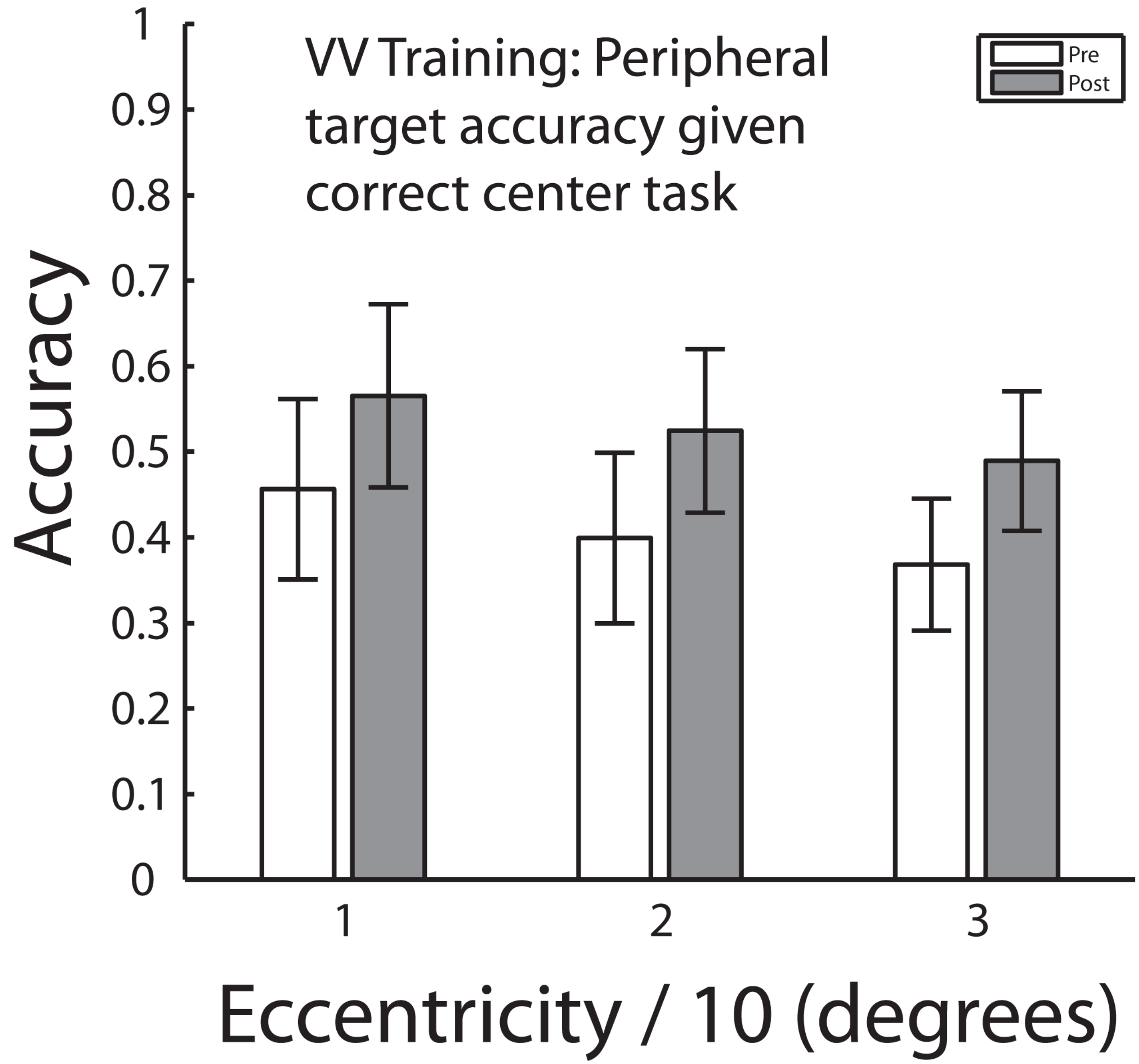


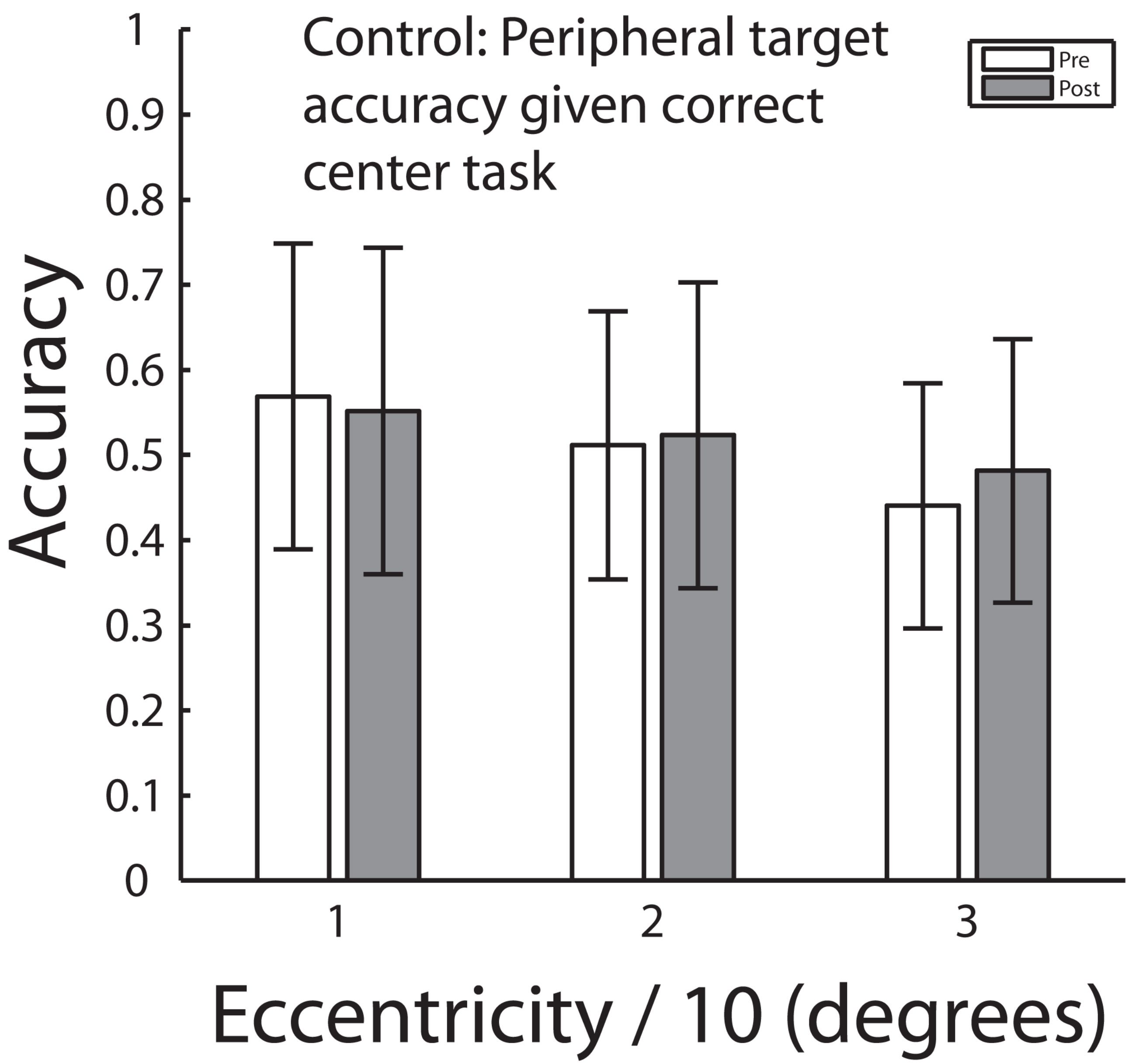
Useful field of view

Can low-level visual cognition be improved through game play?

Mech. Turk Incentive Optimization

\$1 → \$0.5 → \$.03 → \$0.01 → \$0


VV Training: Peripheral target accuracy given correct center task
Pre
Post
Accuracy
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
Eccentricity / 10 (degrees)


Control: Peripheral target accuracy given correct center task
Pre
Post
Accuracy
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
Eccentricity / 10 (degrees)

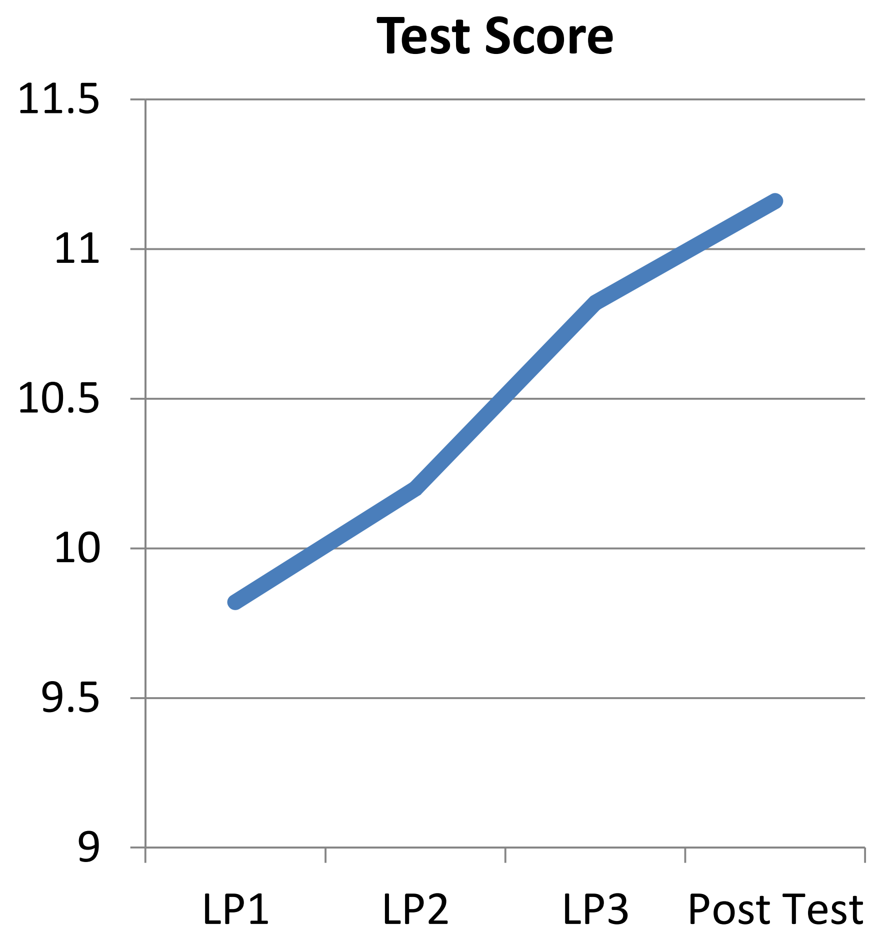
Math Bottlenecks

"Difficulty with fractions… is **pervasive** and is a **major obstacle to further progress** in mathematics."

- US National Mathematics Advisory Panel final report, 2006, 2008

Repeated Gameplay Produces Consistent Improvement

- 4,000 3rd Graders
- Three weekly level packs
- Pretests integrated into gameplay



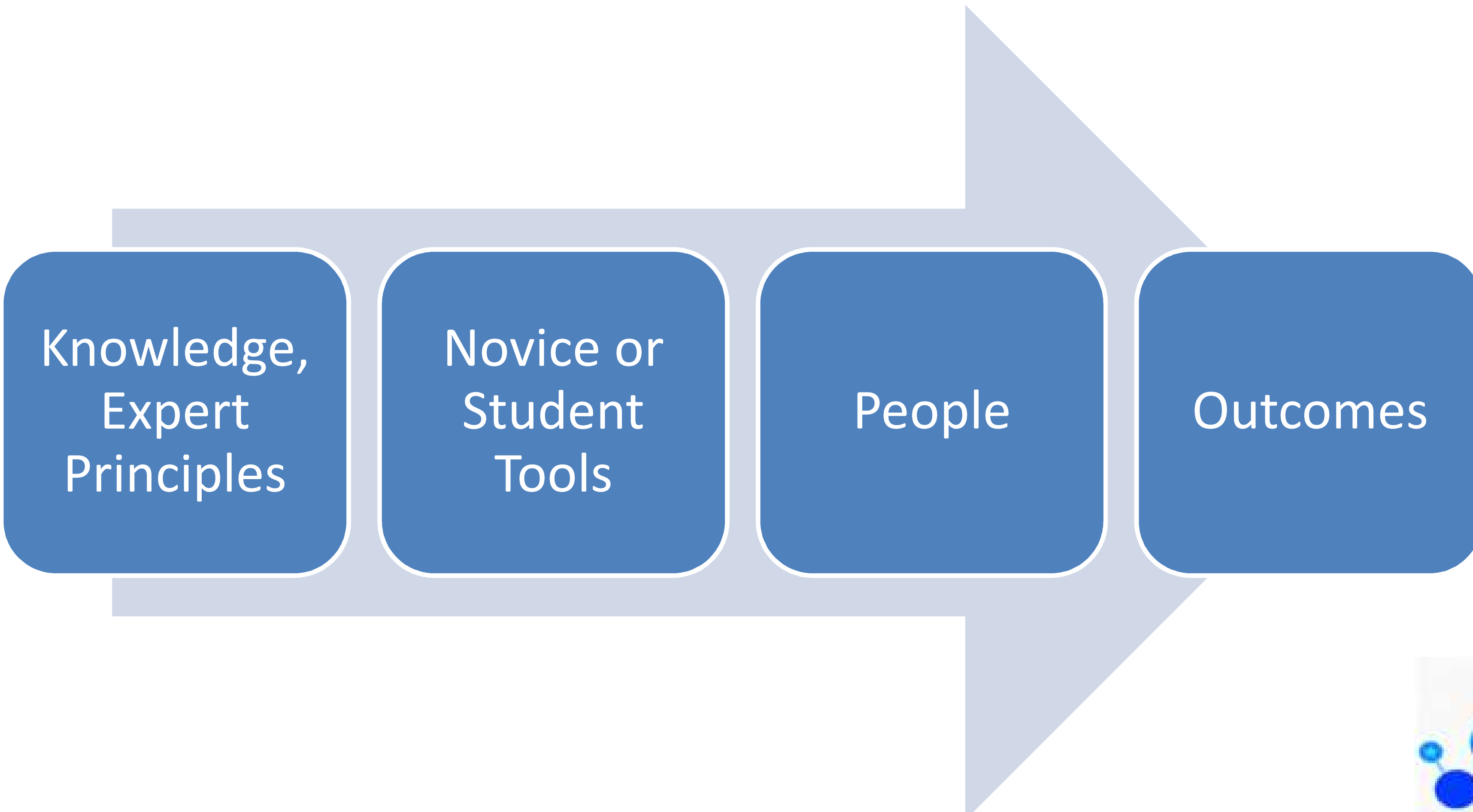
Novice to Experts

In each case,

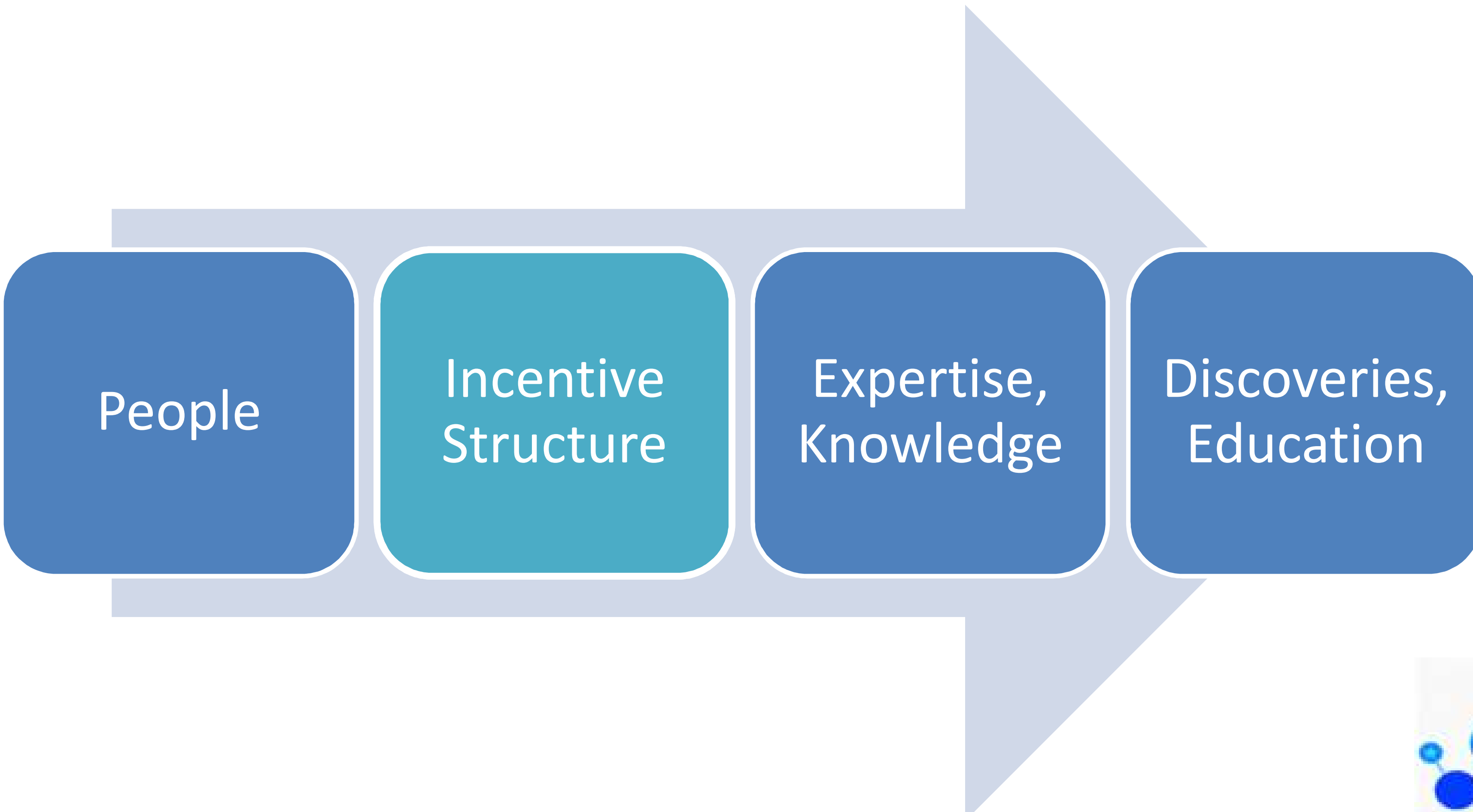
Data-driven evolution
with large number of players is

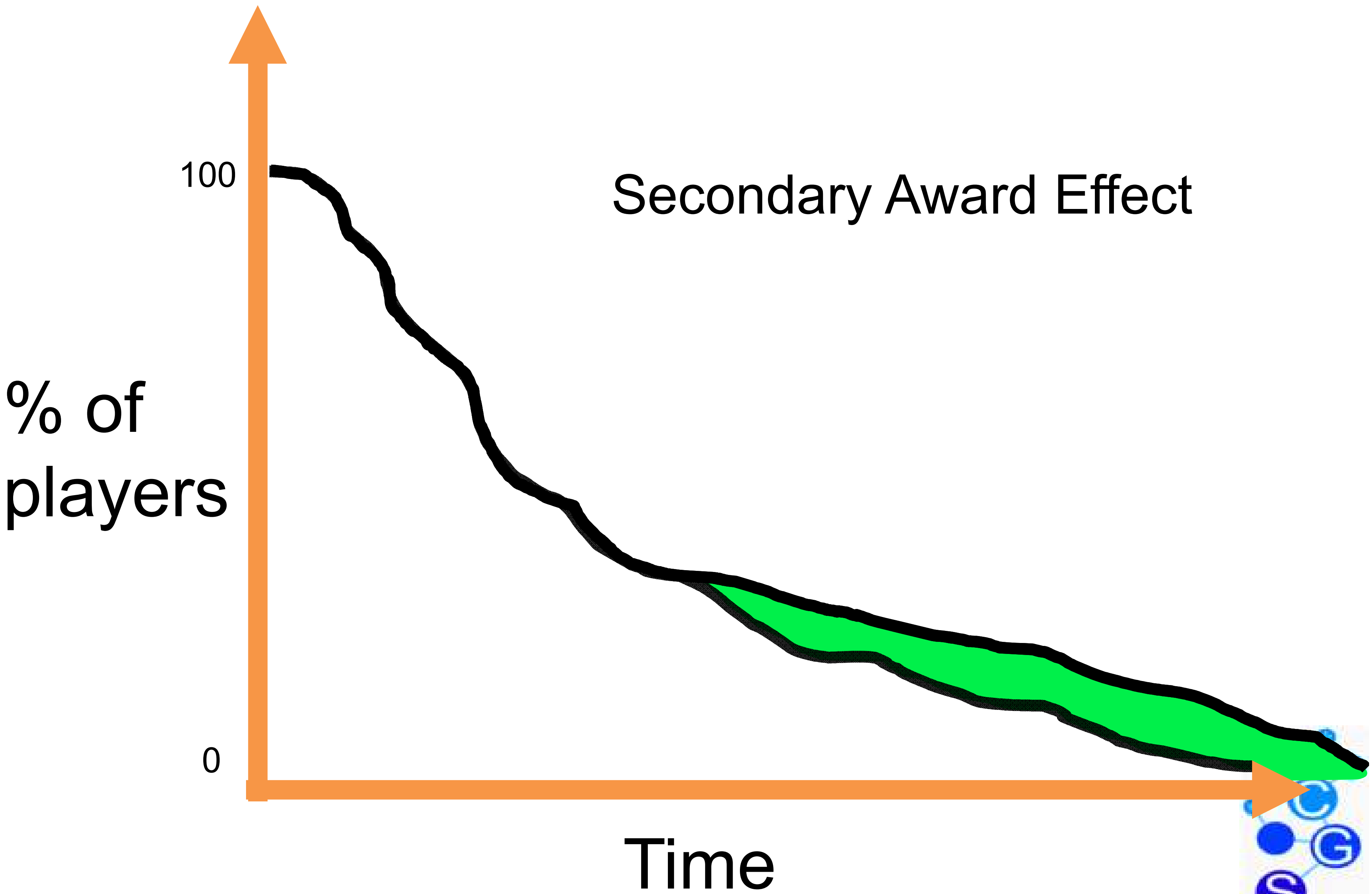
1 to 3 times as long as initial development

Standard trickle down approach

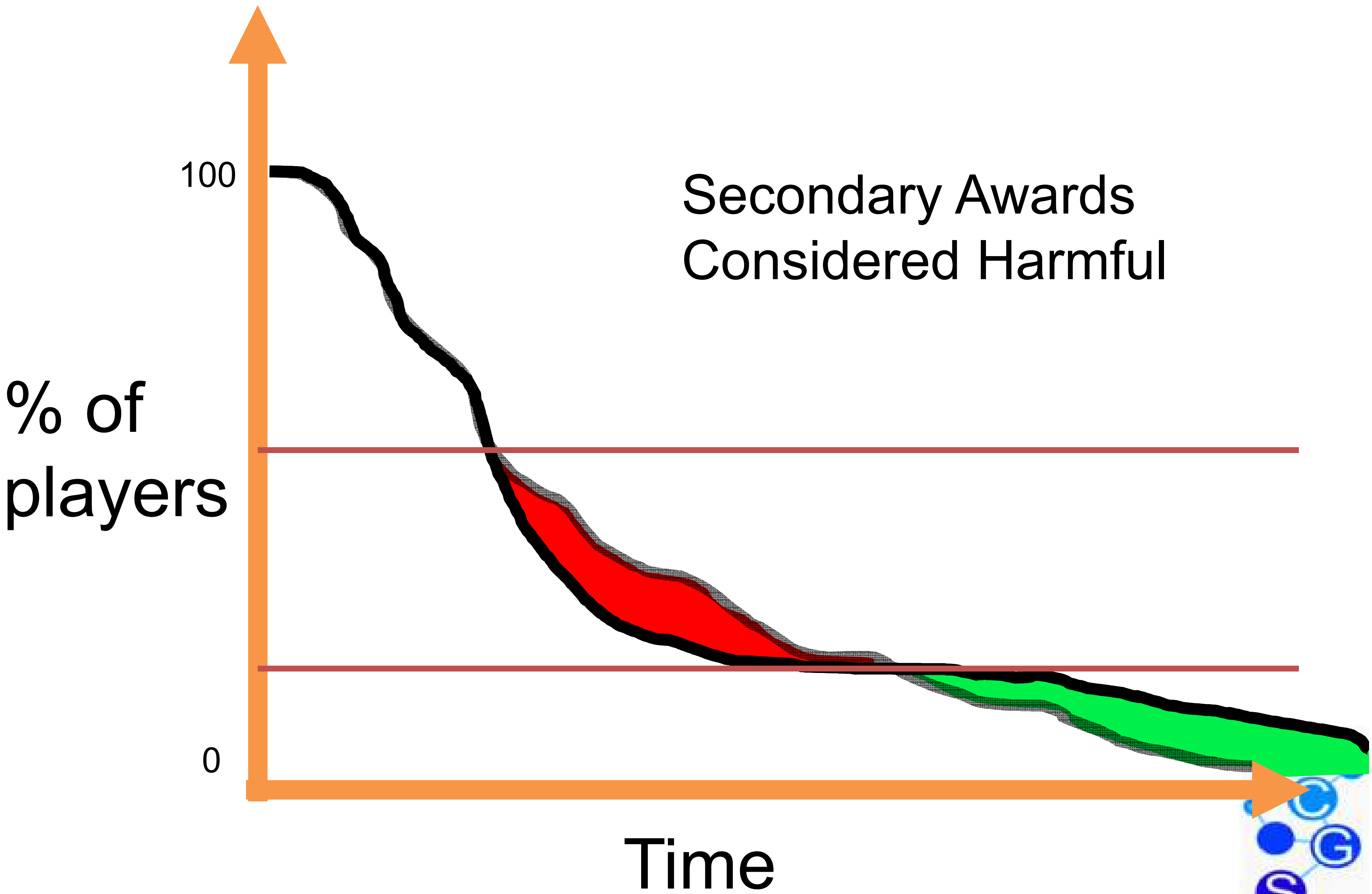


Incentivized Expert Creation

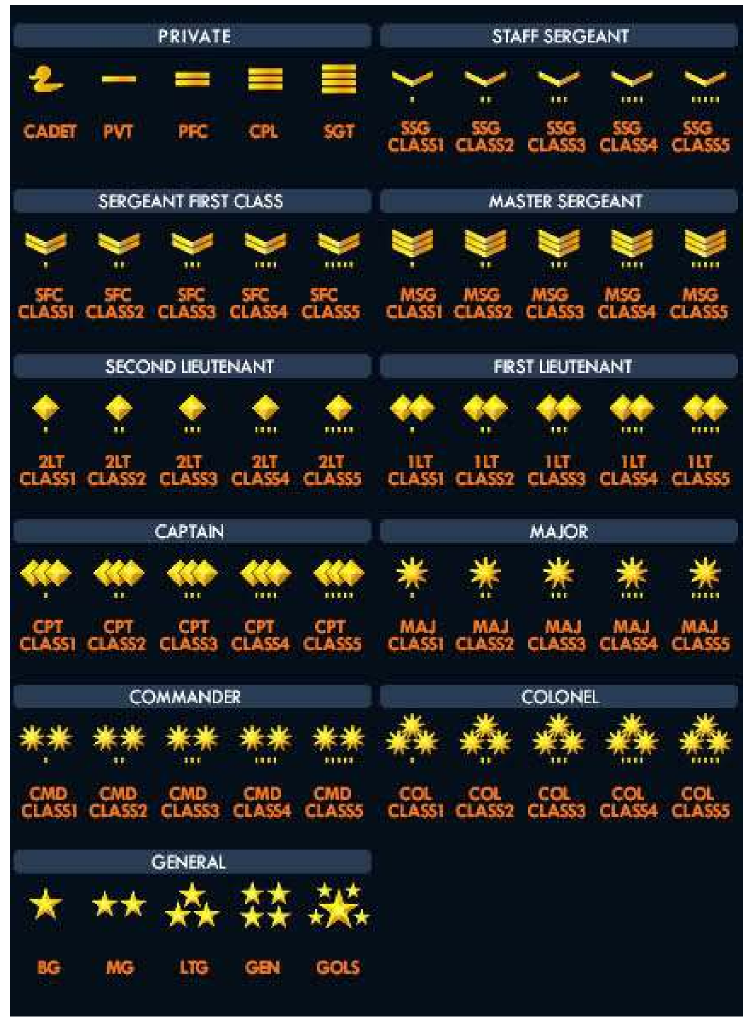



Secondary Award Effect
100
0
% of players
Time

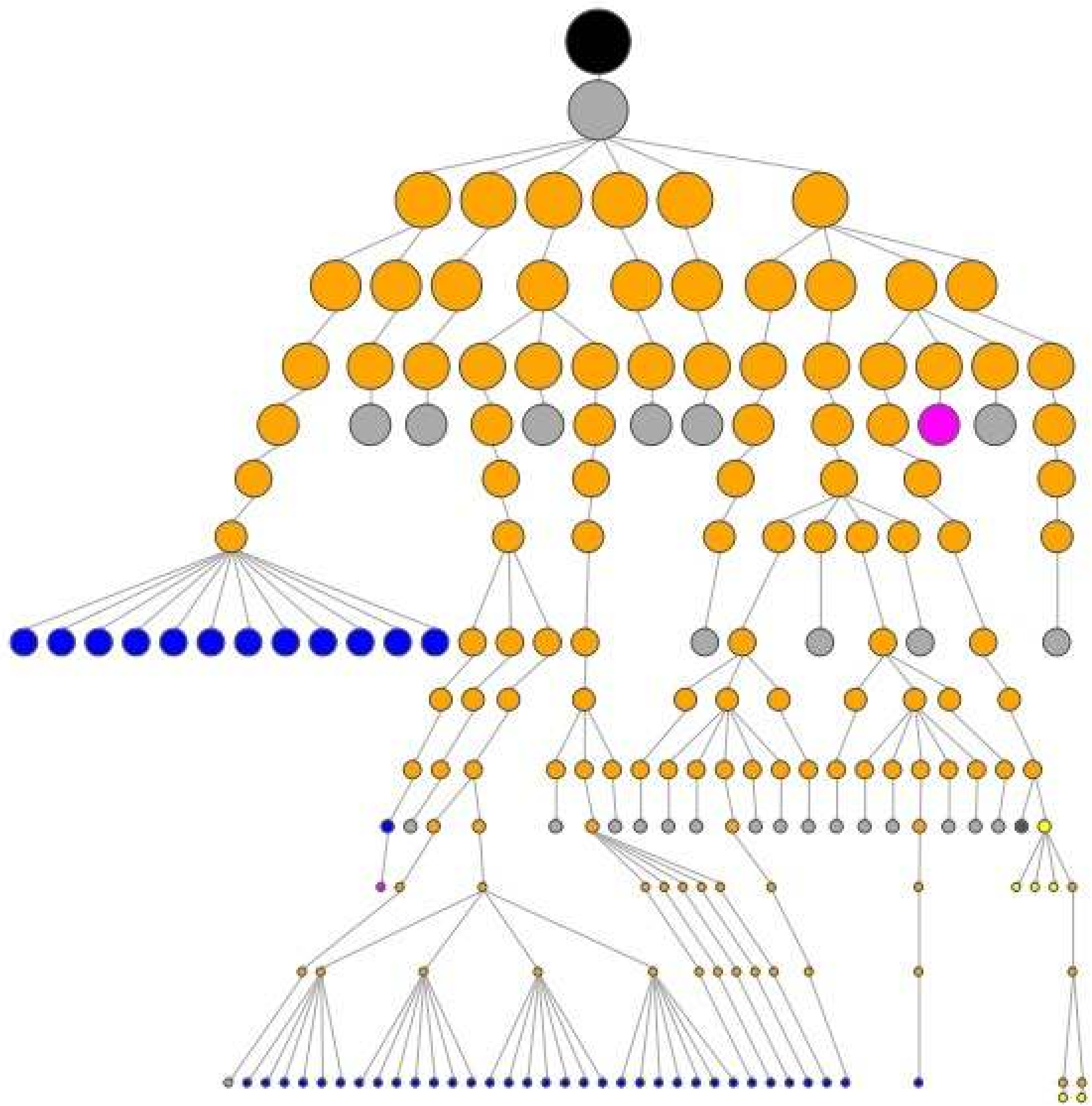
Secondary Awards Considered Harmful



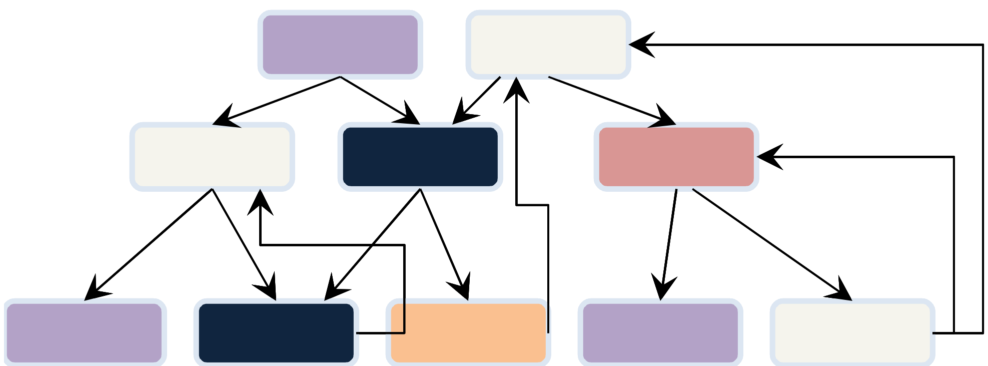
Extrinsic Motivation: short term effect

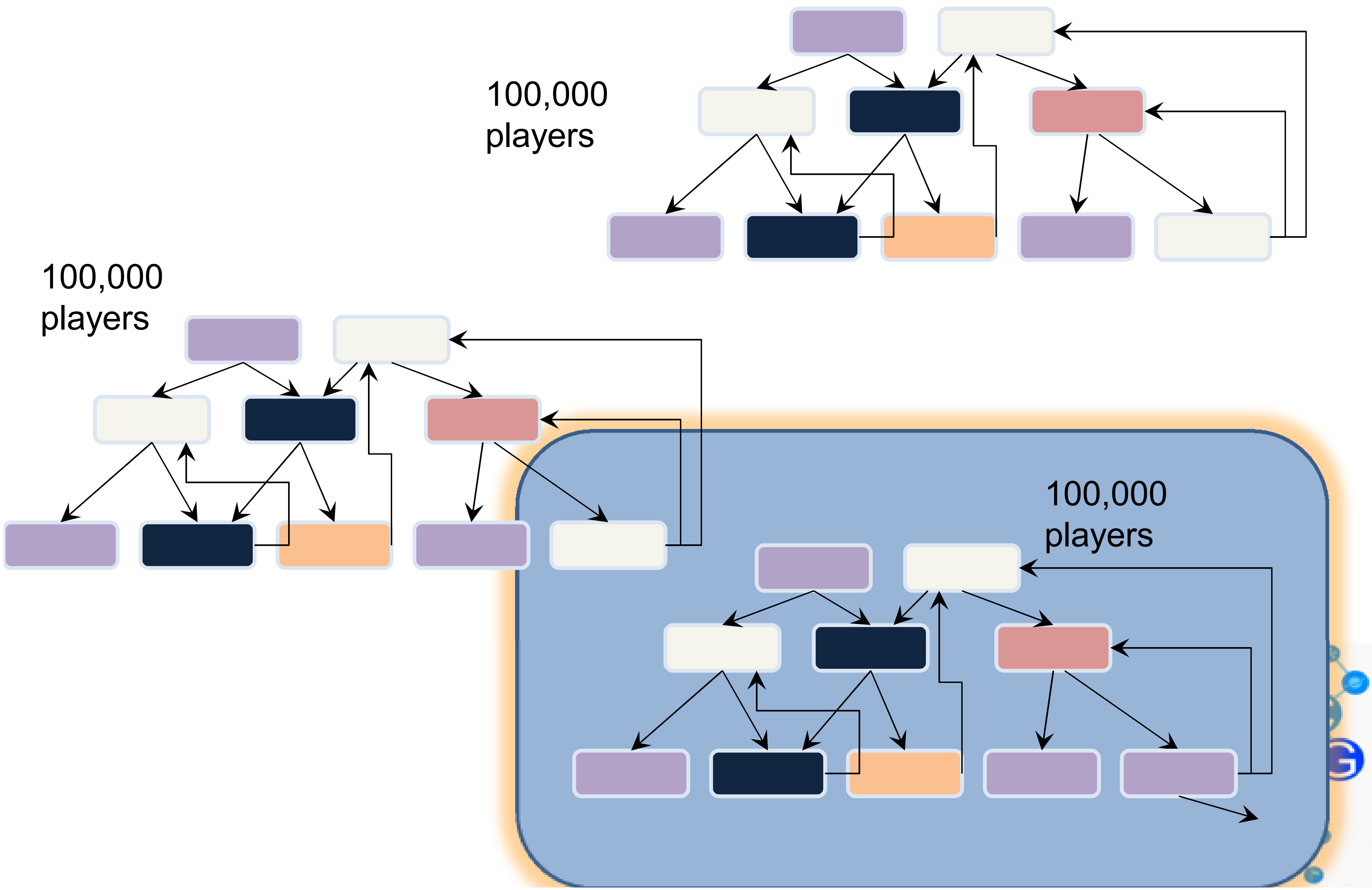


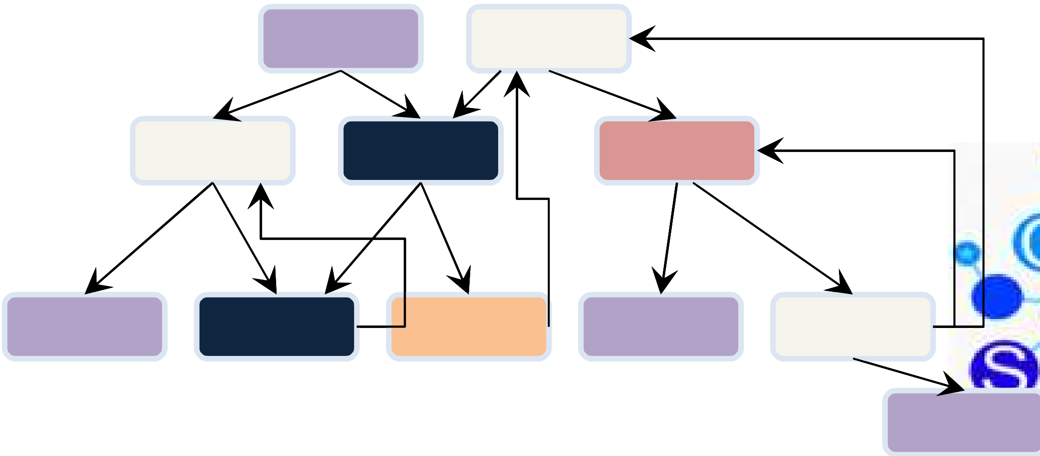
Hierarchical randomized trials



In-game assessment and intelligent tutor refinement




100,000
players
100,000
players
100,000
players



Level Adaptation

- Adapt to maximize long term engagement
- Optimize for persistence
- Expand at the boundary of understanding

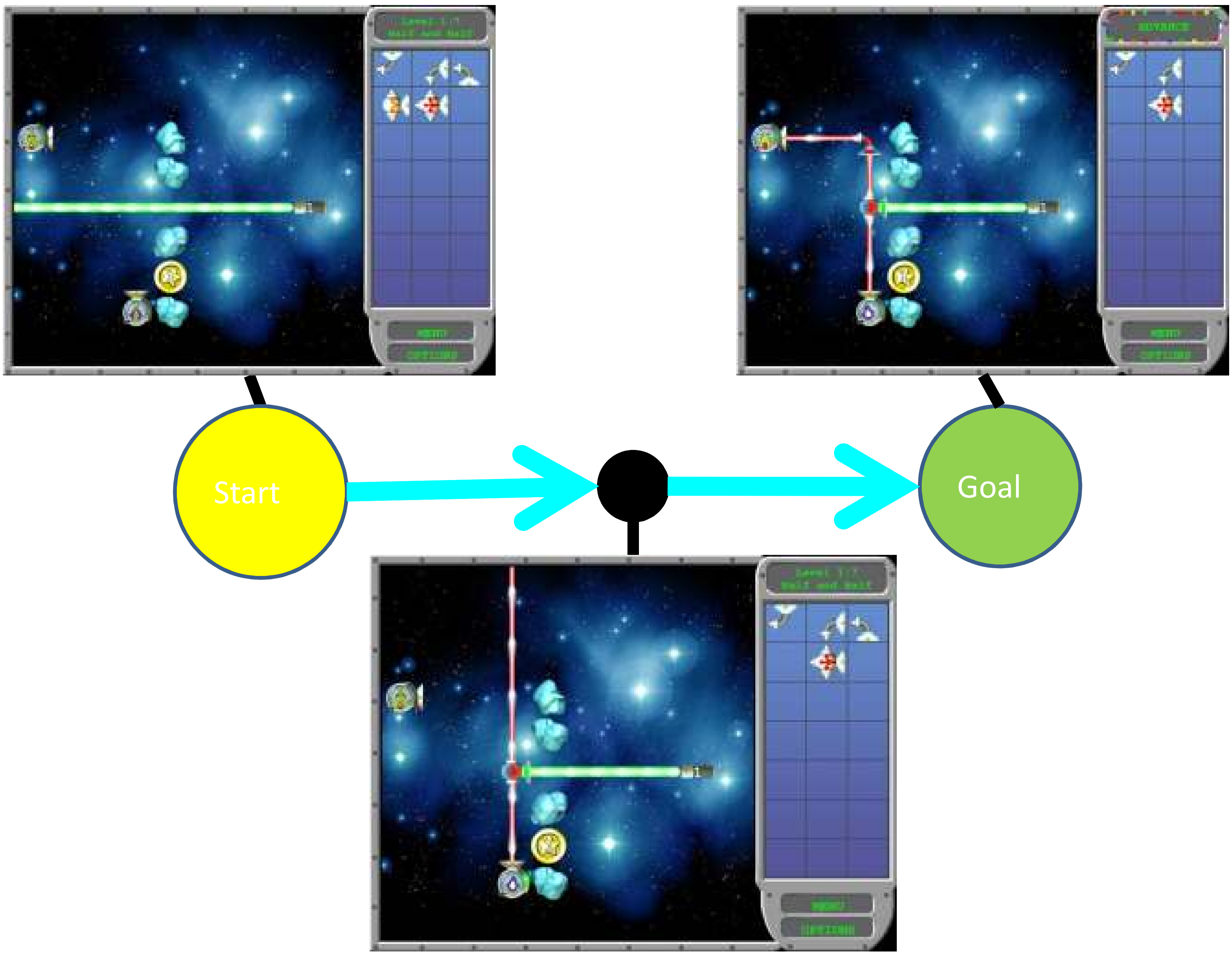
Playtracer Query Tool

```
put_down_wrong_splitter(Action, Trace, Level, Player) :-
       is_action(Action, Trace, Level, Player),
       is_bad_splitter_on_board(Splitter, Level),
       happens(Action, dropped_piece(Splitter)),
```

- Uses logging data to generate facts (e.g., happens)
- Leverages complex query language to encode game-specific logic in rules (e.g., is_bad_splitter_on_board)
- Backed by database system that allows these queries to be run on a large amount data

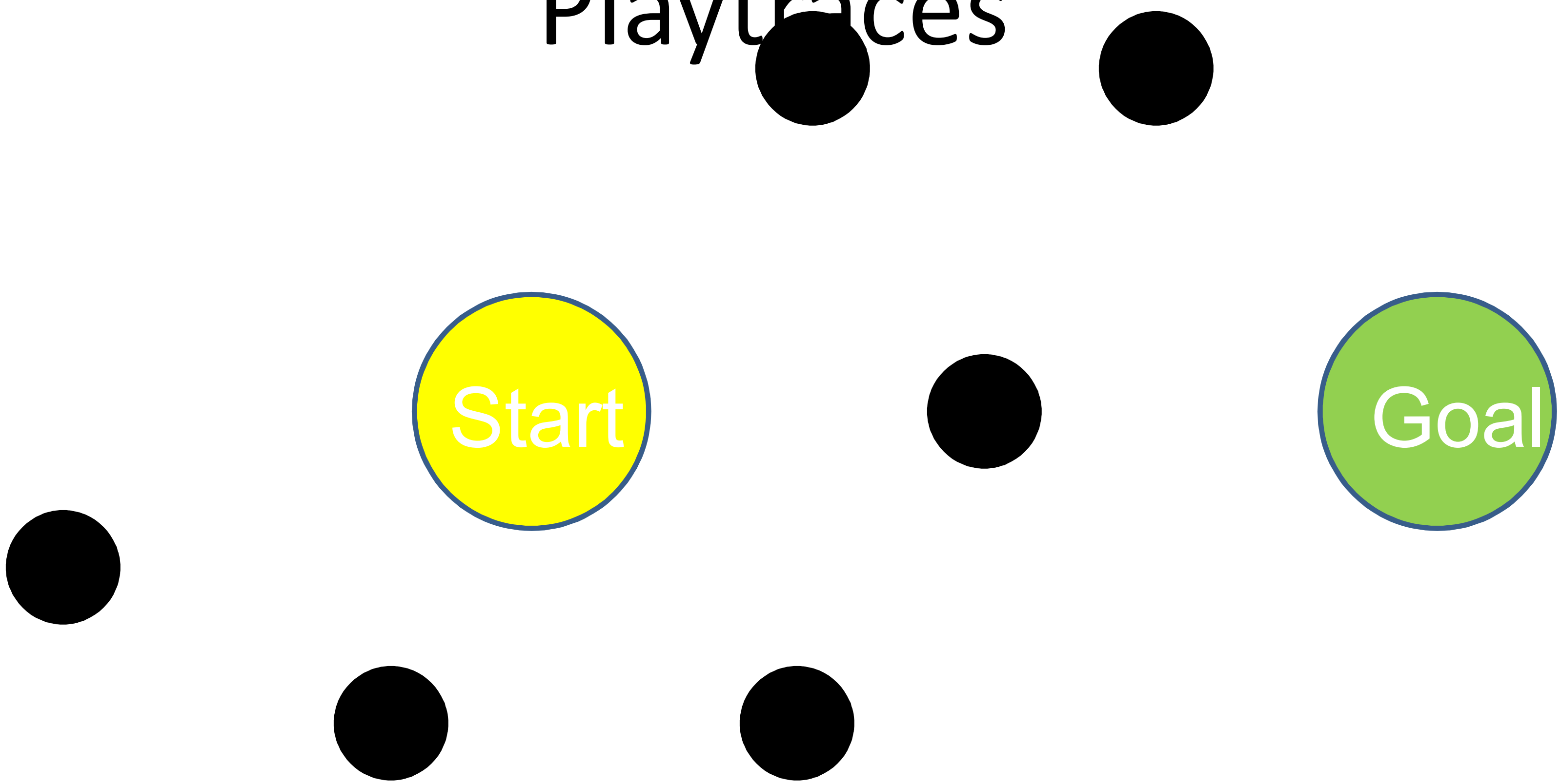
Writing Rules

```
% holds if the user dropped a 2-splitter Piece on Action
did_drop_2splitter(Action, Piece) :-
        happens(Action, drop(Piece, _)),
        action(Action, Trace),
        trace(Trace, _, Level),
        holds(Level, piece_type(Piece, splitter2)).

% action A2 happens after A1 in the same trace
% assumes next_action is correctly defined
later_action(A1, A2) :- next_action(A1, A2).
later_action(A1, A3) :-
        next_action(A1, A2),
        later_action(A2, A3).

% holds if the user dropped a 2-splitter Piece on A1
% but then picked it up later on A2
dropped_2splitter_then_picked_it_up(A1, A2, Piece) :-
        did_drop_2splitter(A1, Piece),
        happens(A2, pickup(Piece)),
        later_action(A1, A2).
```

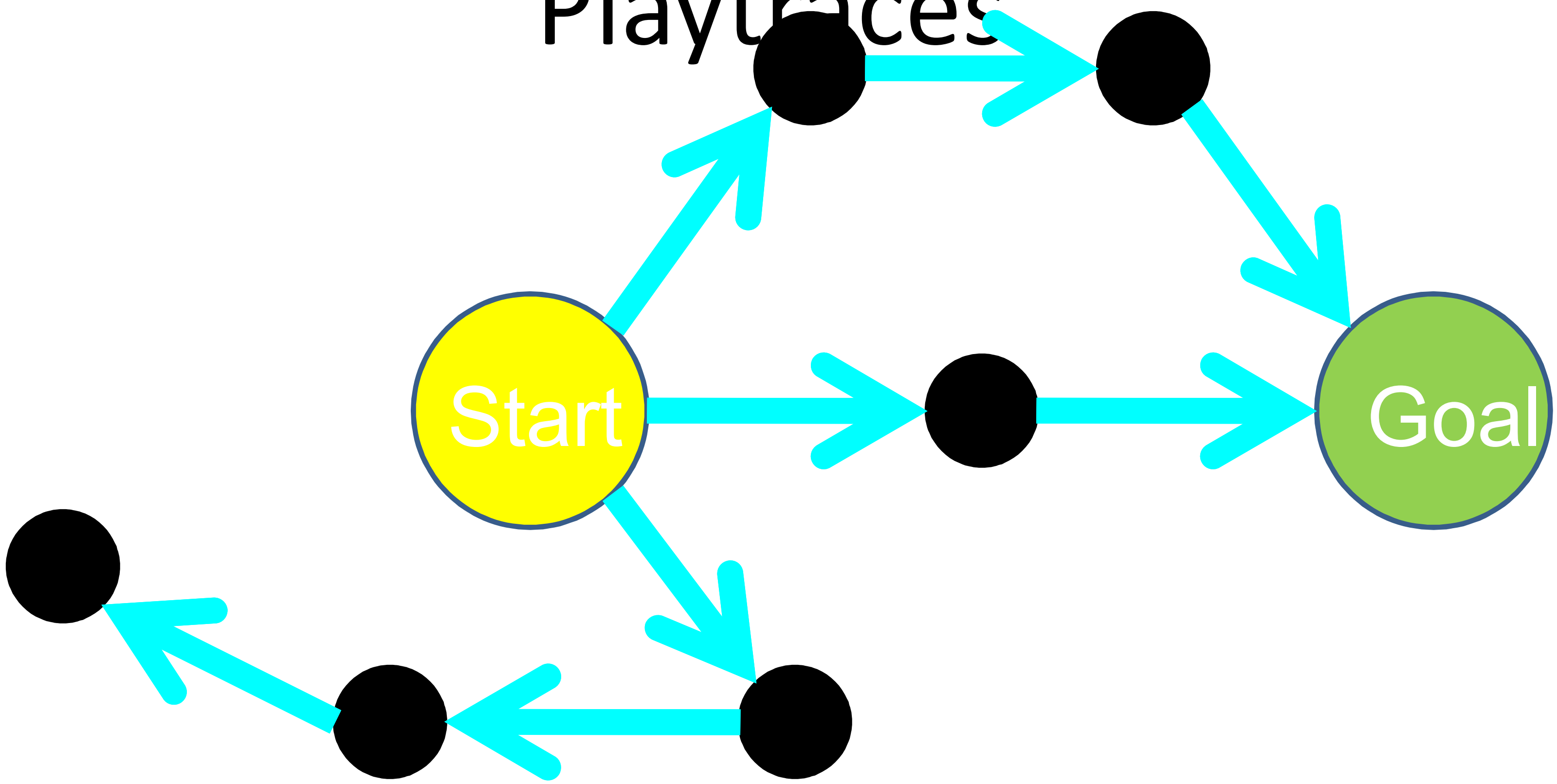

Start
Goal

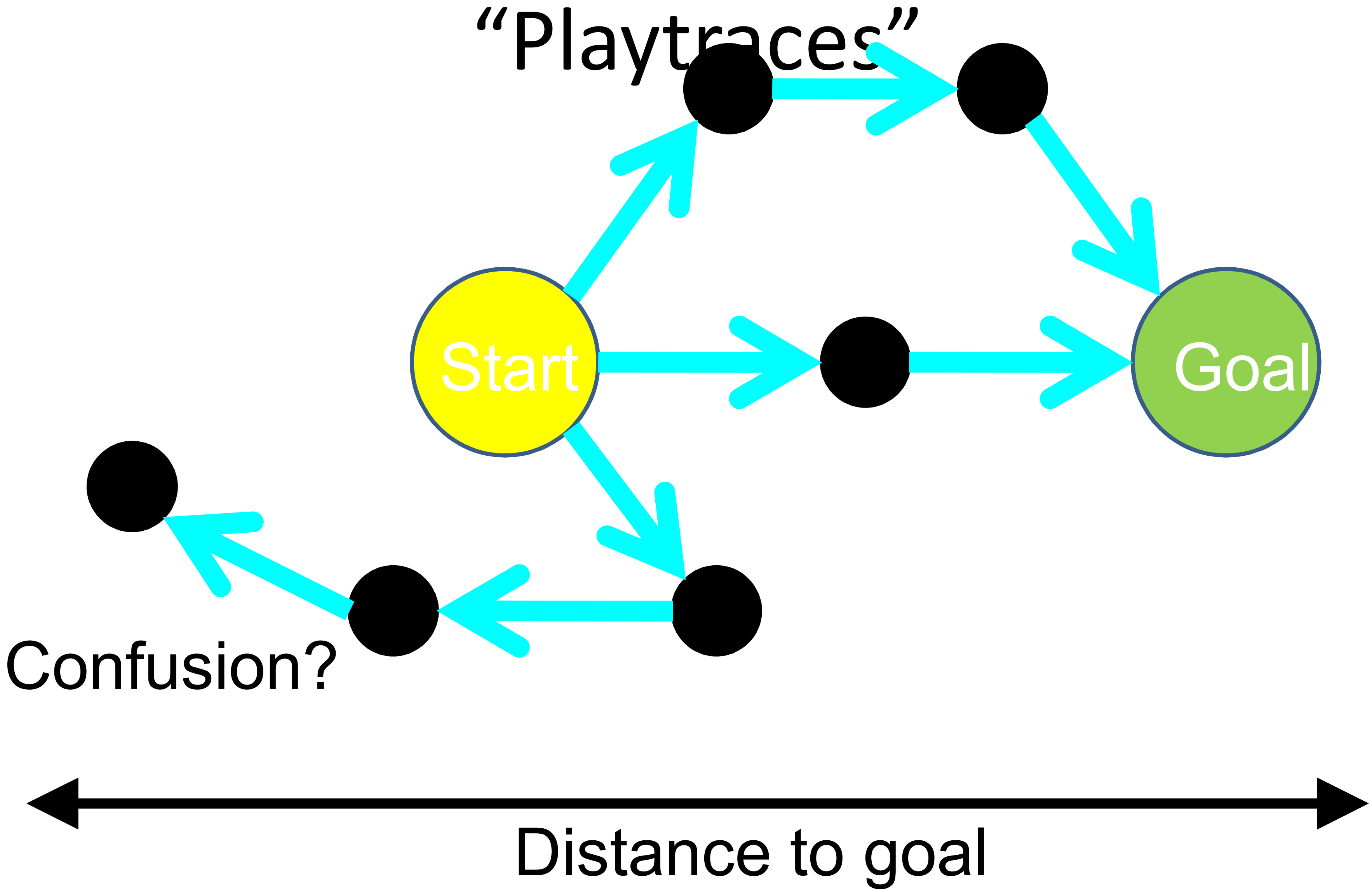
“Playtraces”

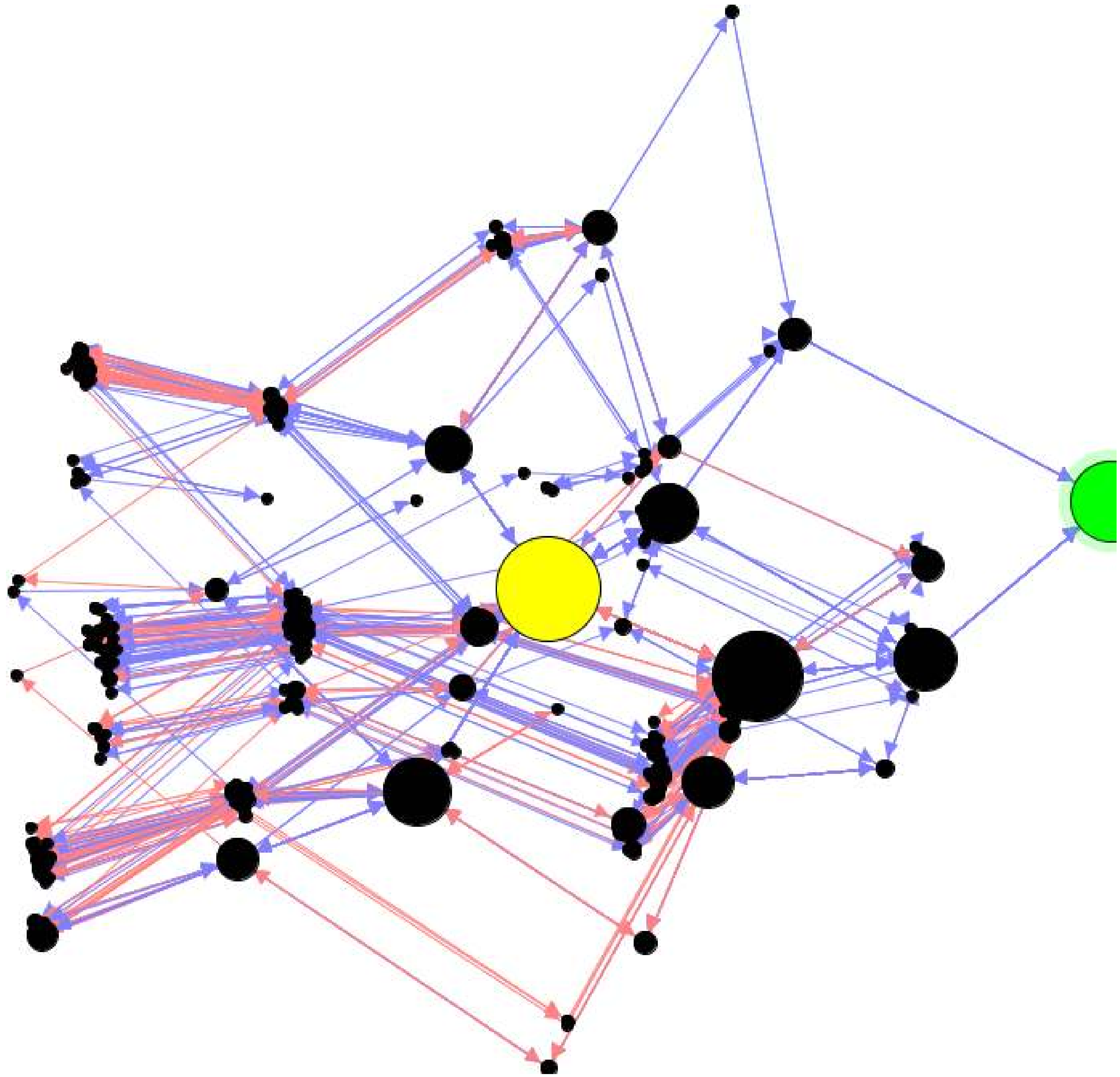
“Playtraces”

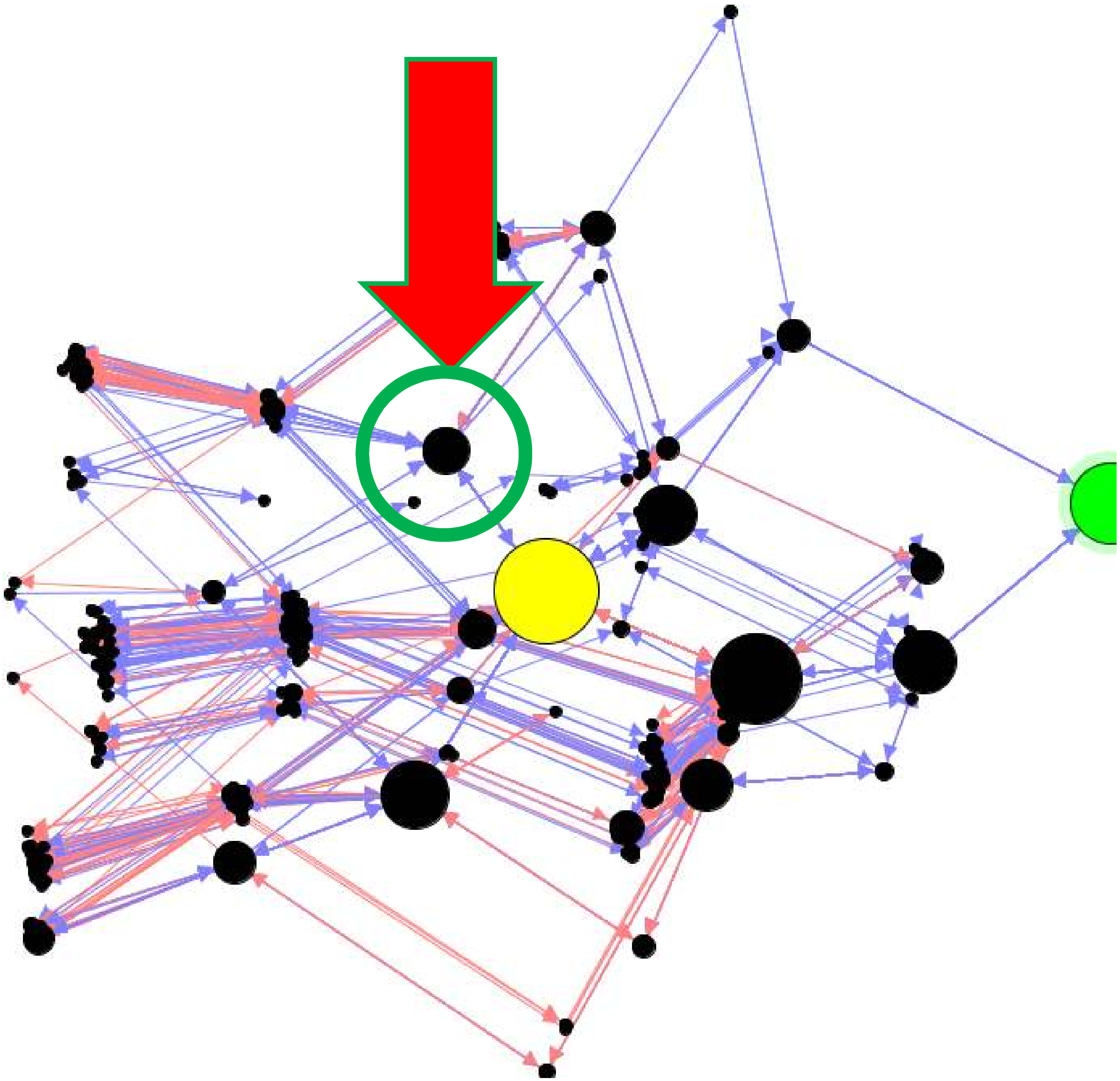


“Playtraces”

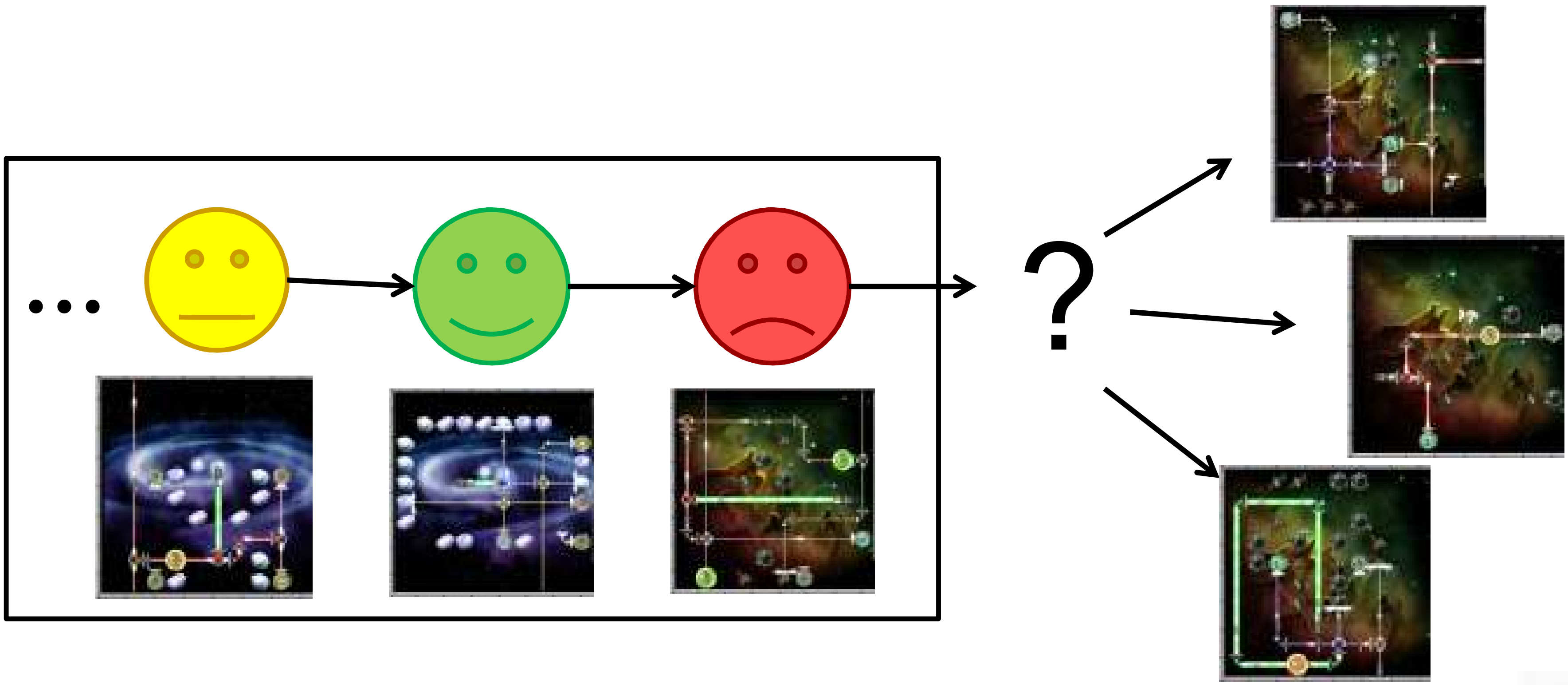



"Playtraces"
Start
Goal
Confusion?
Distance to goal

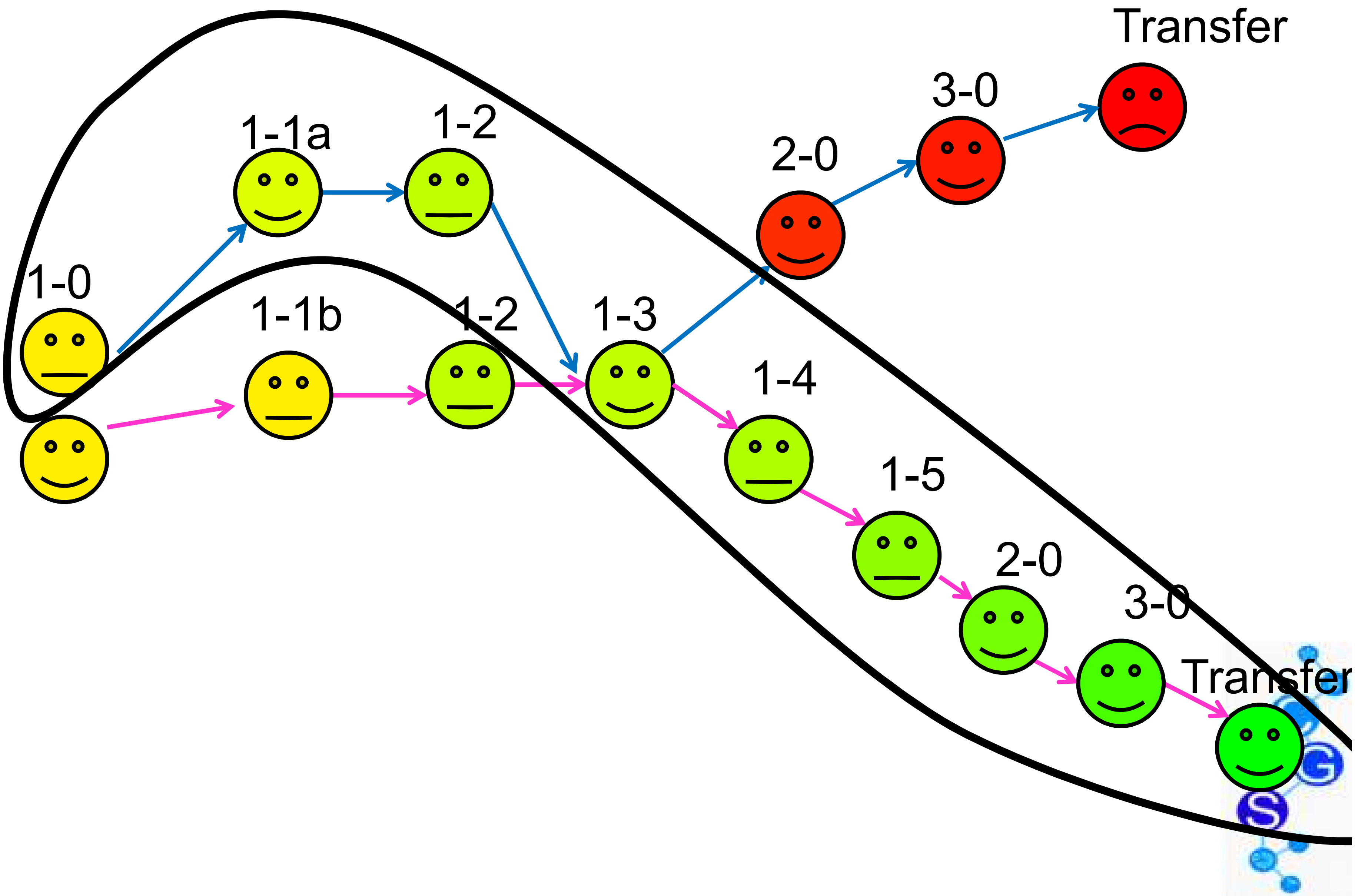


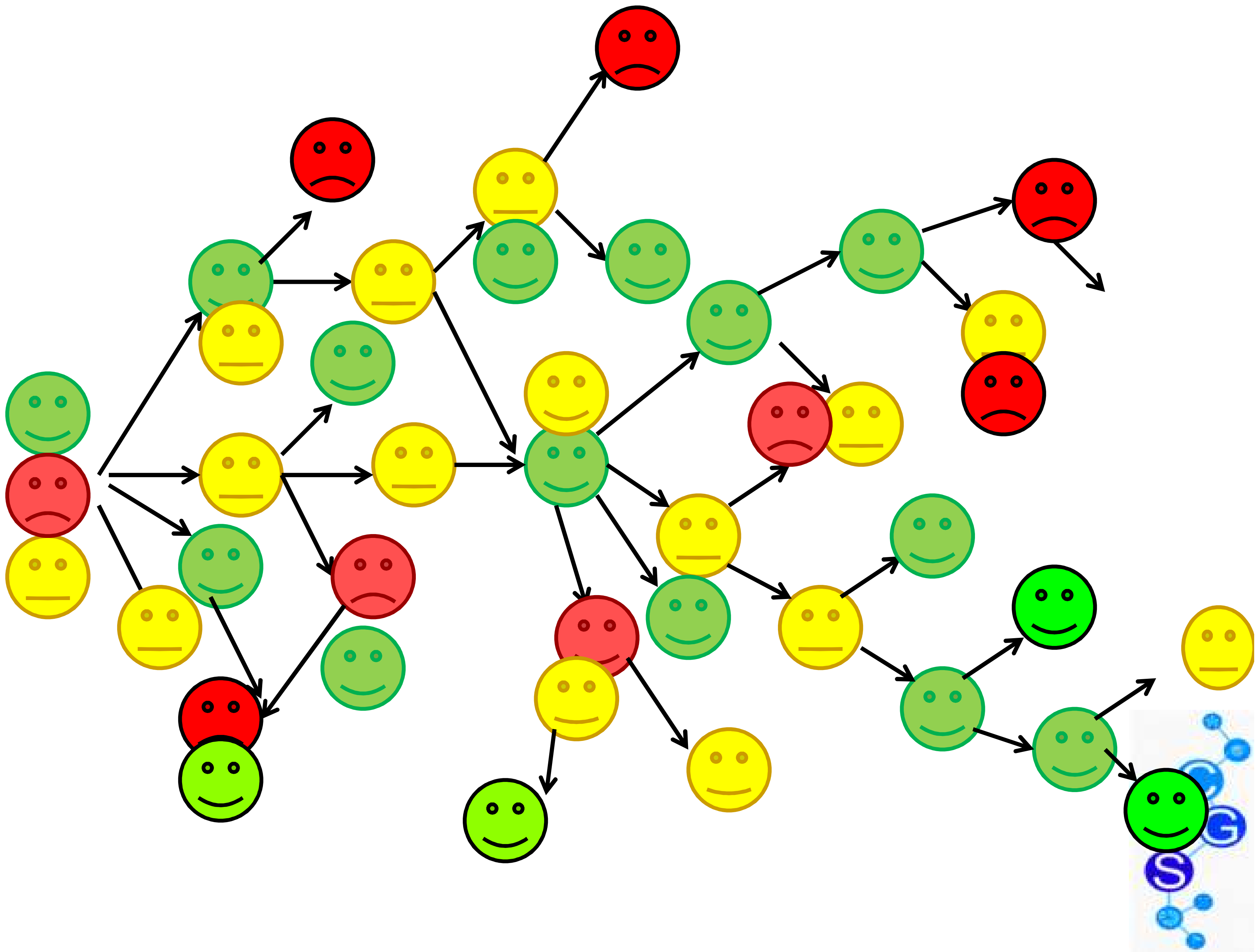


Reinforcement Learning problem

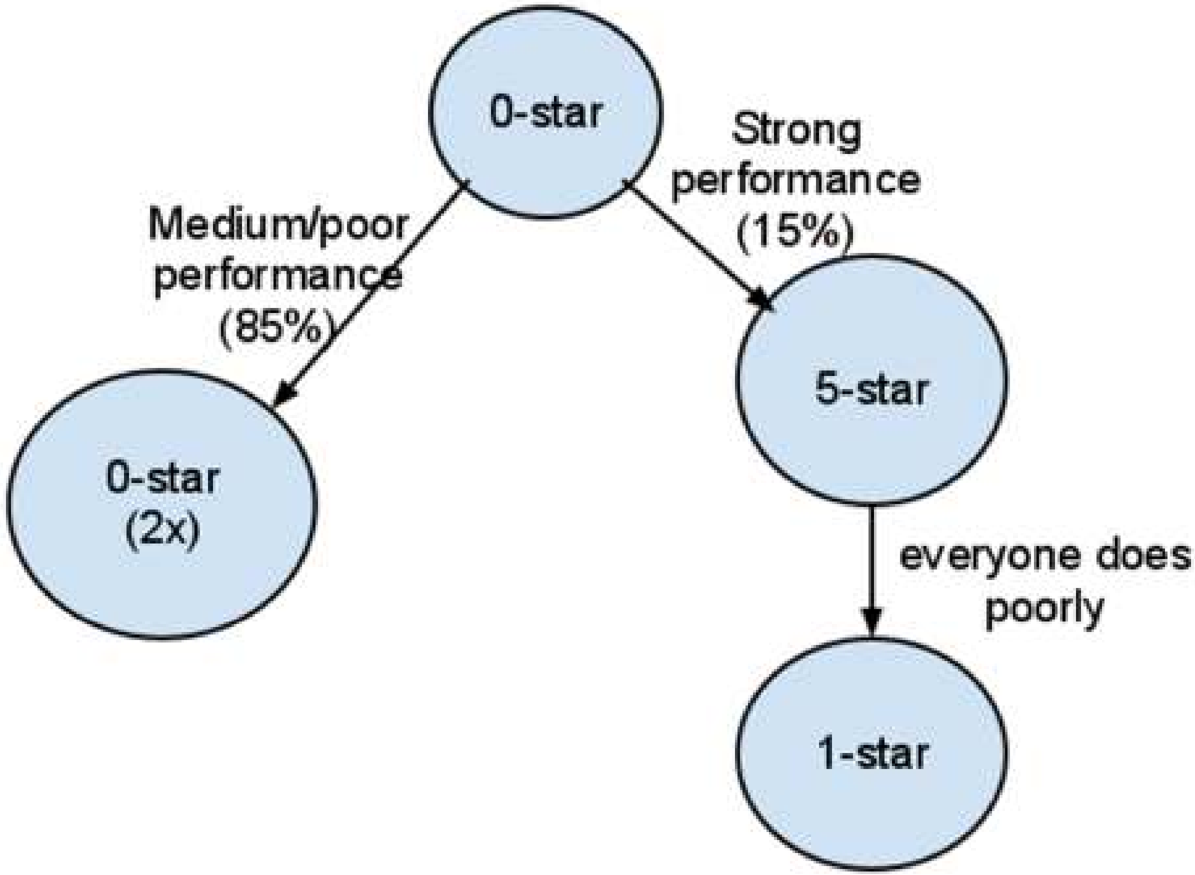


Goal: Maximize student's learning & engagement


Transfer
3-0
1-1a
1-2
2-0
1-0
1-1b
1-2
1-3
1-4
1-5
2-0
3-0
Transfer



Early Experiment



Key RL experiments

- Dwell Time (Time on Task)

A A A B B B AB AB

A B AB C ABC D ABCD

- Challenge layering

… ABC D AD BD CD ABD ACD ABCD

… ABC D ABCD E ABCDE

- Challenge Ordering

B BC A ABC

AB C ABC F D FD ABCDF

Key RL experiments

- Optimal hinting strategies
- Persistence and tenacity
- Long-term effects on domains
- Self-identification

Effects of hinting depth

Two 1/3 Ships:

- (1) "Try this piece" <point to the 3-splitter>
- (2) "To make 1/3, split the laser in three"
- (3) "How much power do the ships need?"

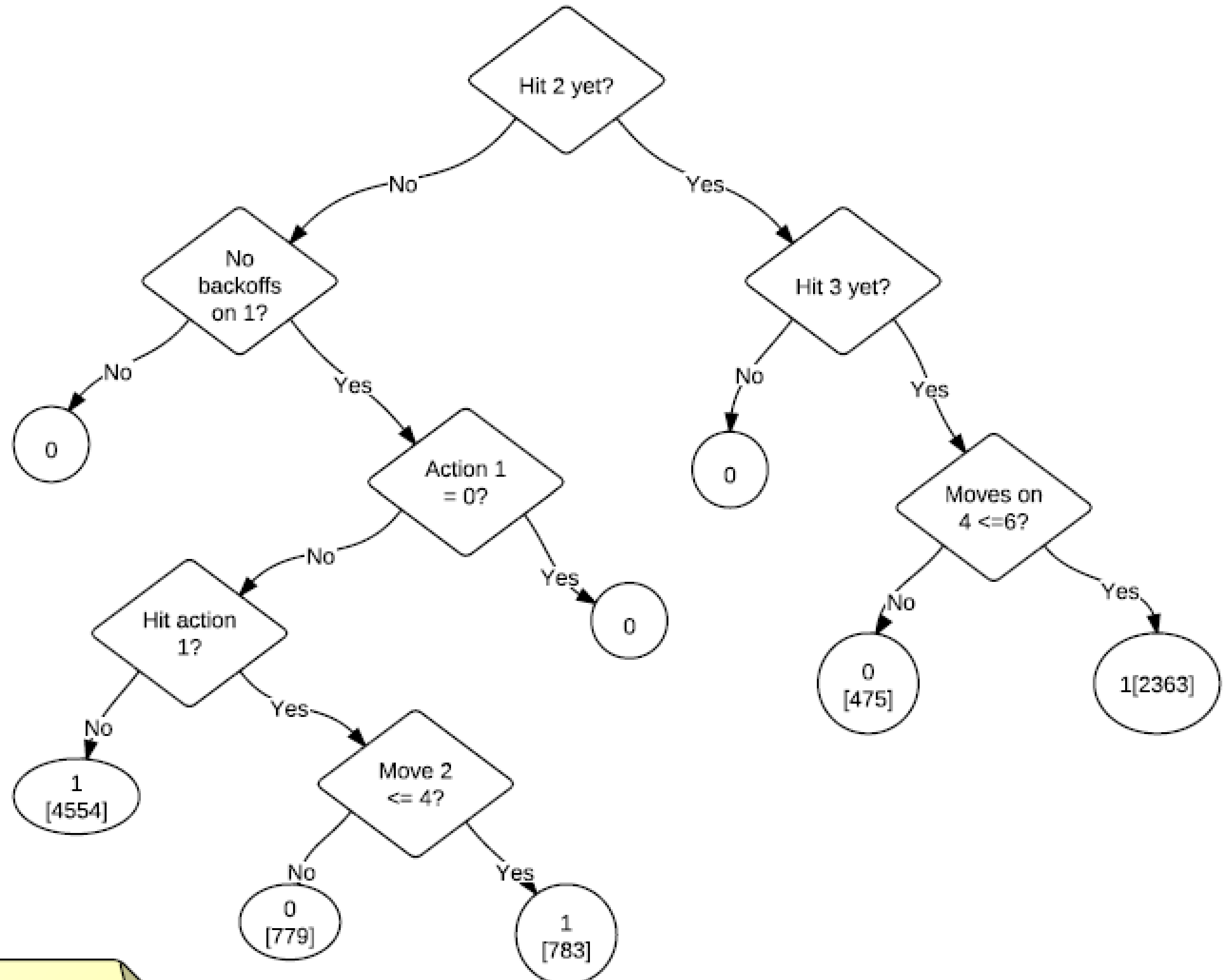
Make 1/4:

- (1) "Try using BOTH two-splitters" <point to one two-splitter>
- (2) "To make 1/4, split the laser two times"
- (3) "None of the pieces split into four. How do you make 1/4?"

Split Ordering:

- (1) "Try this piece first" <point to three-splitter>
- (2) "Split the laser in thirds first"
- (3) "Which splitter should you use first?"

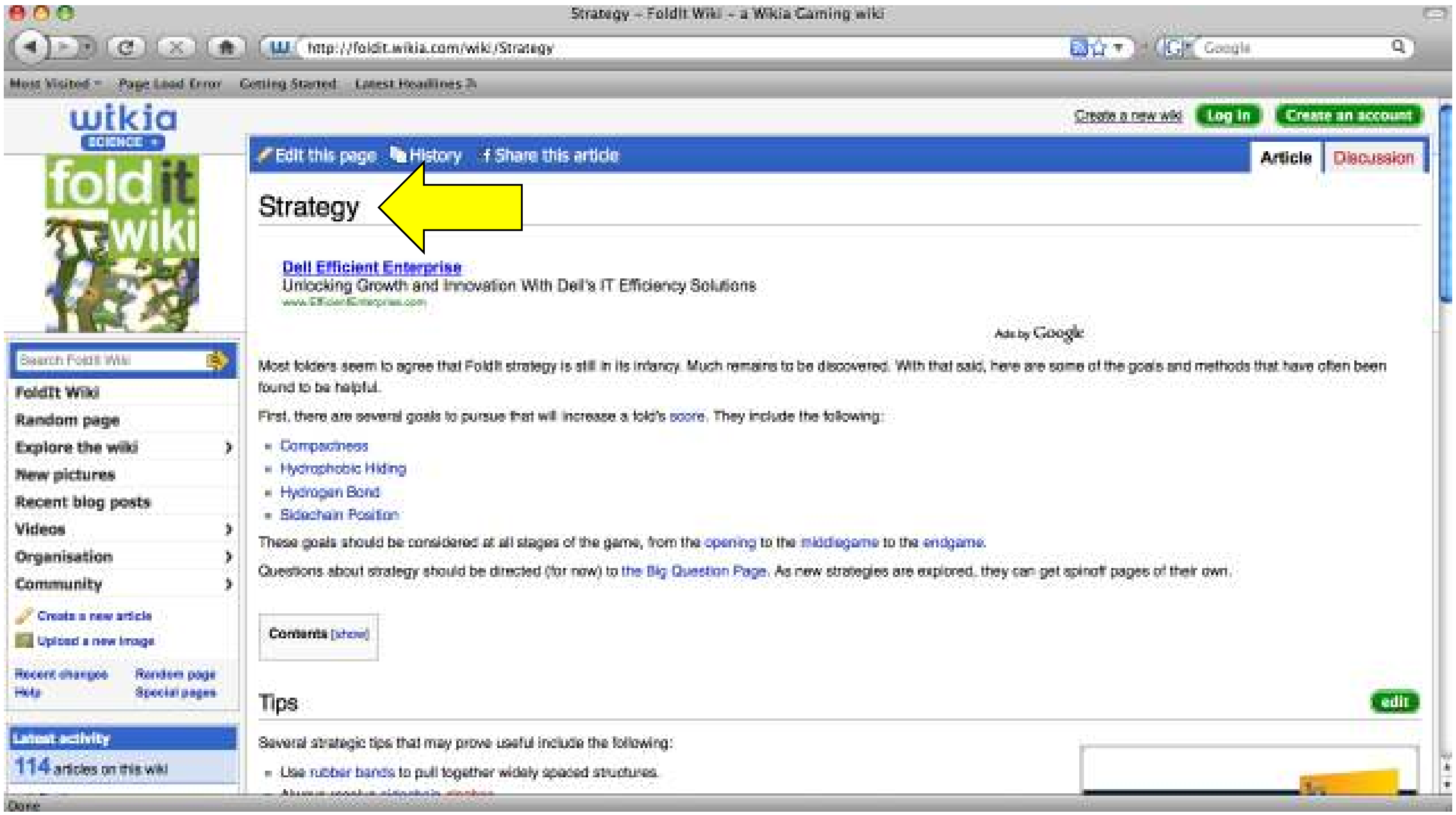
RL Policy


Hit 2 yet?
No
Yes
No backoffs on 1?
Hit 3 yet?
No
Yes
0
Action 1 = 0?
No
Yes
0
Moves on 4 <=6?
No
Yes
Hit action 1?
Yes
0
No
Yes
0 [475]
1[2363]
No
Yes
1 [4554]
Move 2 <= 4?
No
Yes
0 [779]
1 [783]

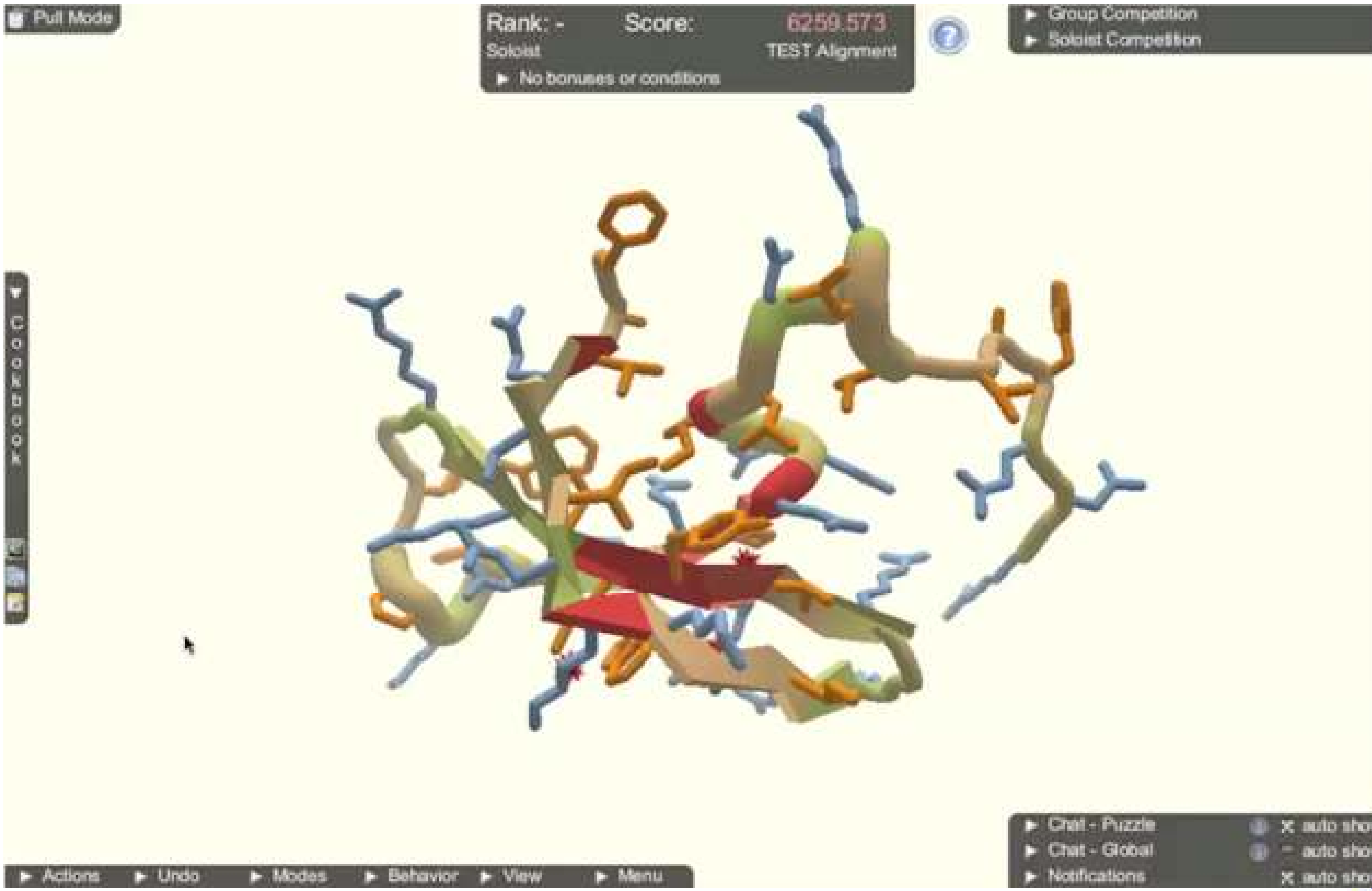
Social elements

- Team play
  - Direct realtime collaboration
  - Collective inteligence
  - Team competition
- Peer tutoring
- Intrinsic Motivation

Player Strategy Wiki

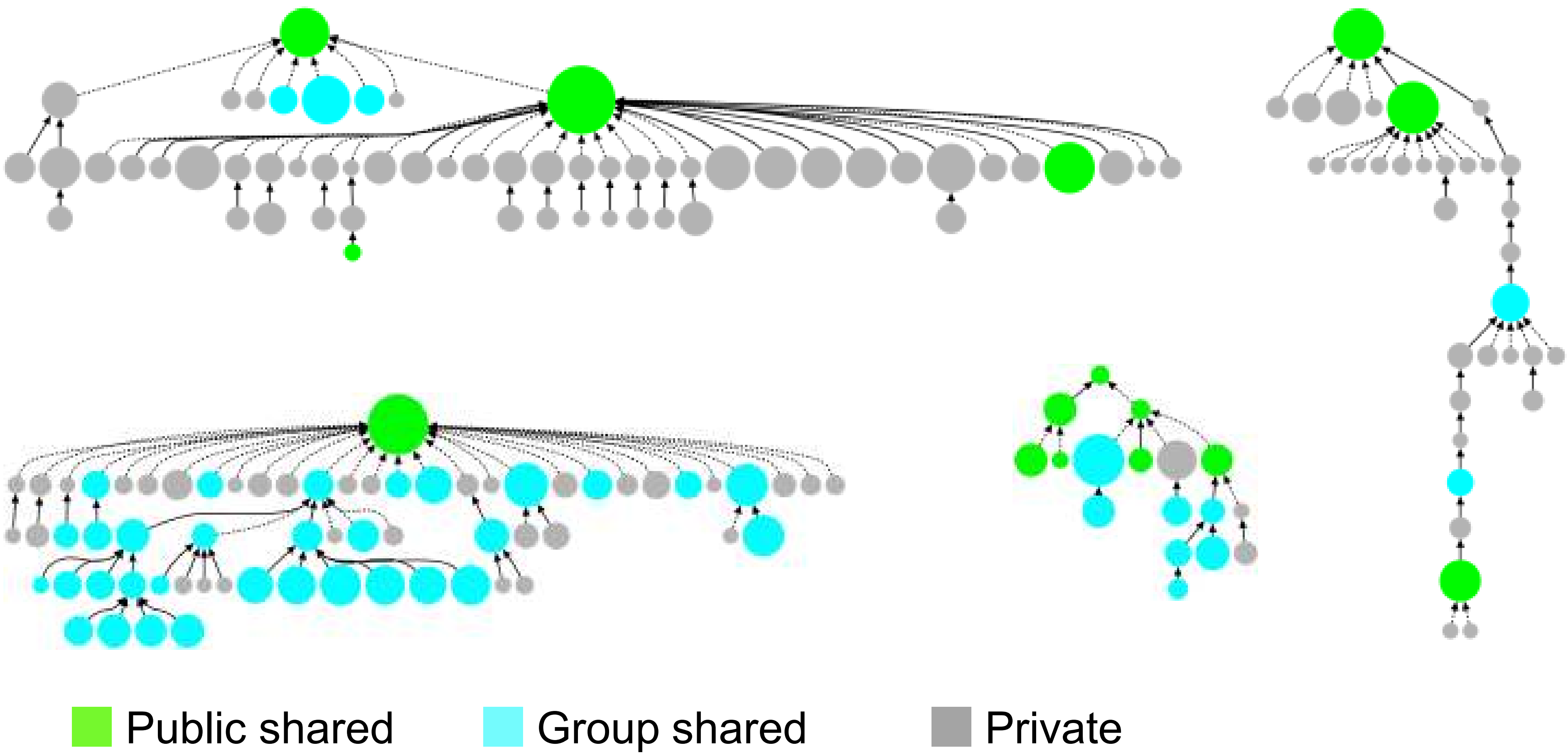


Foldit Cookbook



88% of players run others' recipes

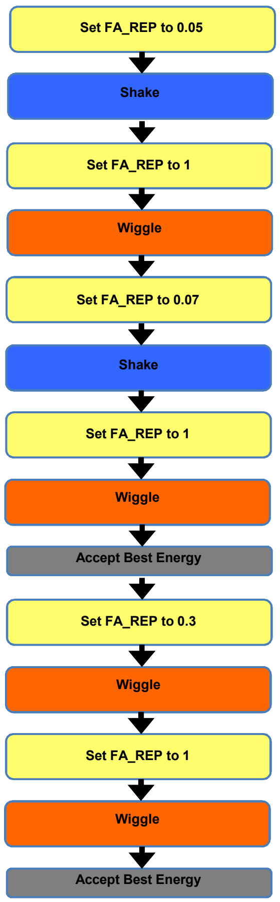
32% of players run only others' recipes



players are taking and modifying shared recipes

Algorithm Comparison

Player Algorithm (Blue Fuse v1.1)

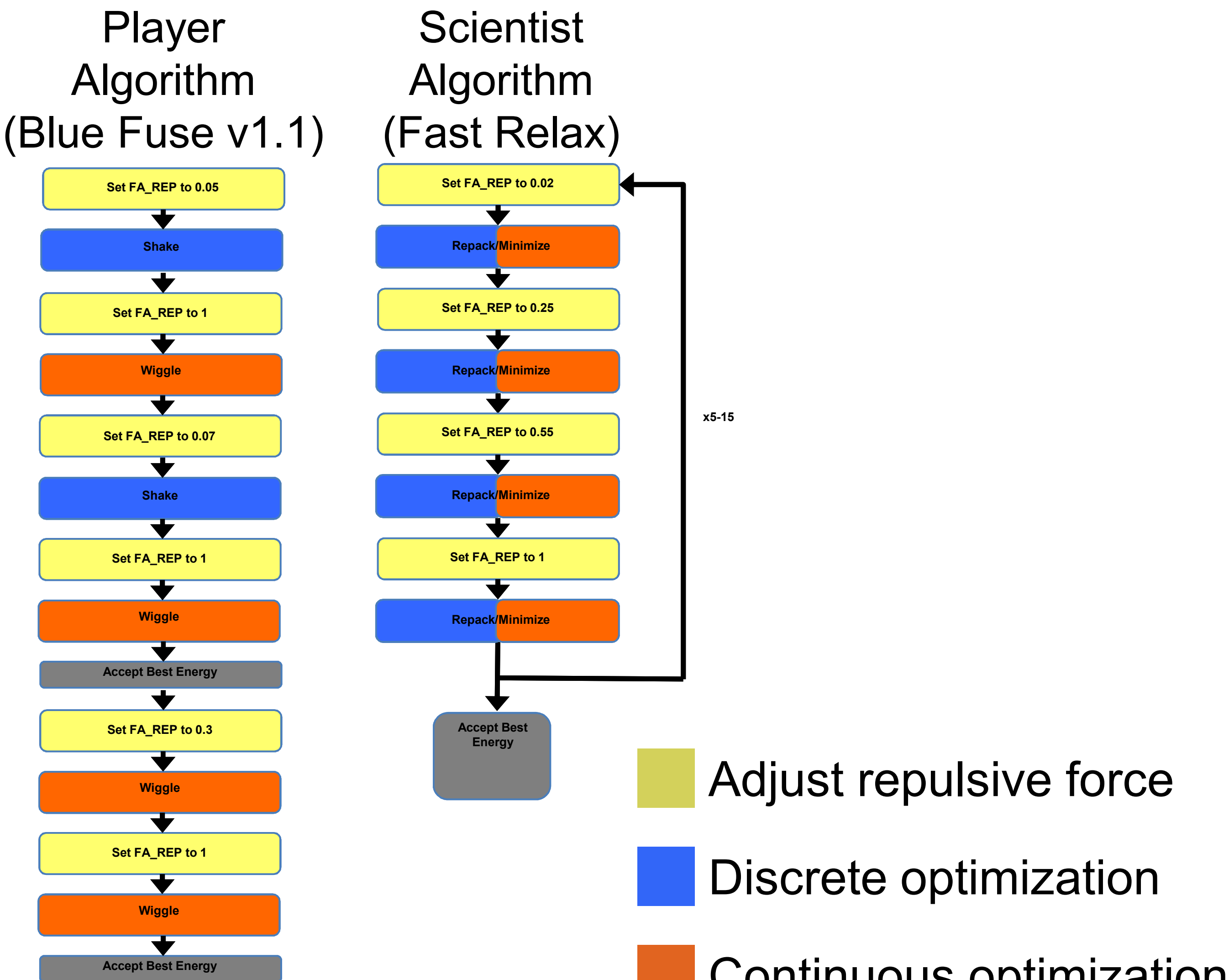


Adjust repulsive force

Discrete optimization

Continuous optimization

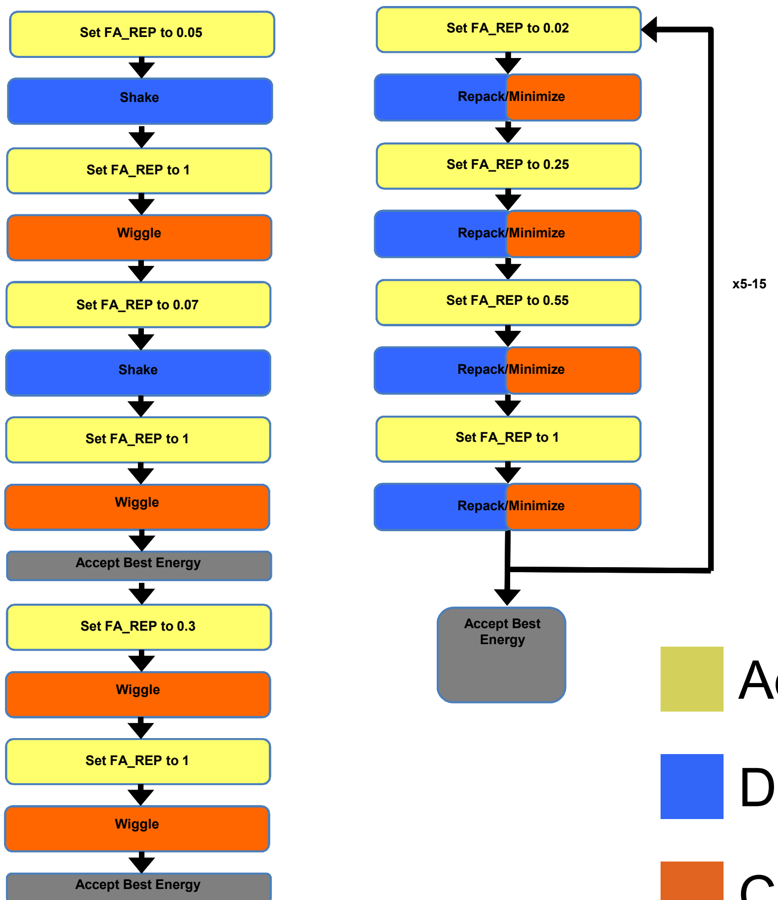
Algorithm Comparison



Algorithm Comparison

Player Algorithm (Blue Fuse v1.1)

Scientist Algorithm (Fast Relax)



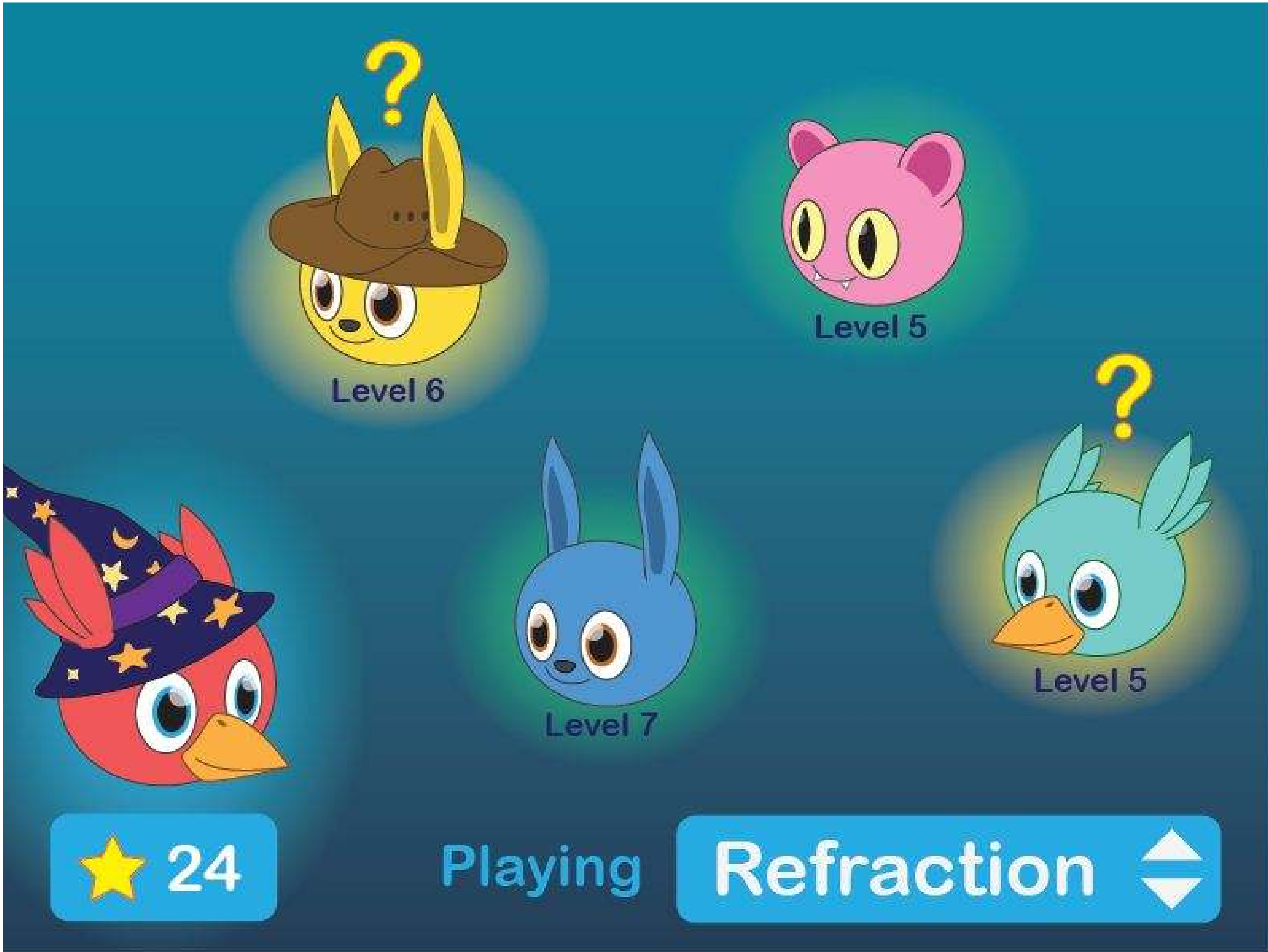
- Independent discovery of scientists' algorithmic techniques

Adjust repulsive force

Discrete optimization

Continuous optimization

Self Identification


Level 6
Level 5
Level 7
Level 5
24
Playing
Refraction


Questions
Hints
Level 4:4
MENU
OPTIONS
Look here - it might be important!

Iterative dual objective optimization

Program plan

Our reality