Adaptive FPGA Placement Optimization via Reinforcement Learning

Kevin E. Murray and Vaughn Betz

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Reinforcement Learning & CAD

CAD Tool Development: Human-in-the-loop

Large solution space → Use heuristics

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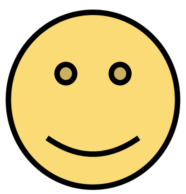

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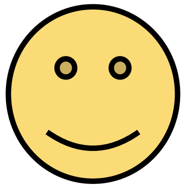
Idea



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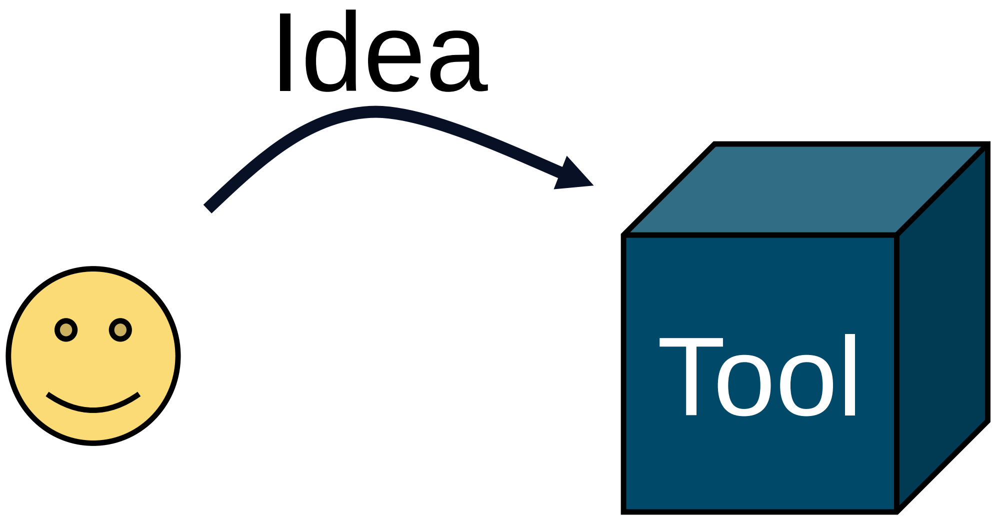

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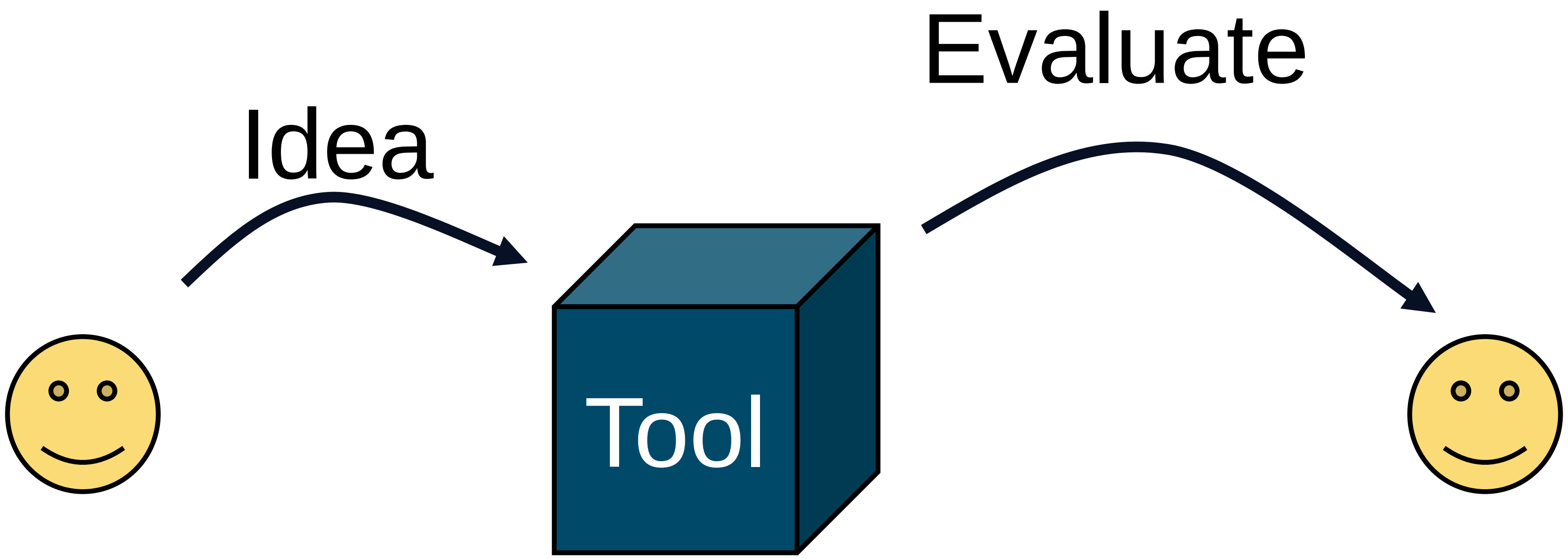

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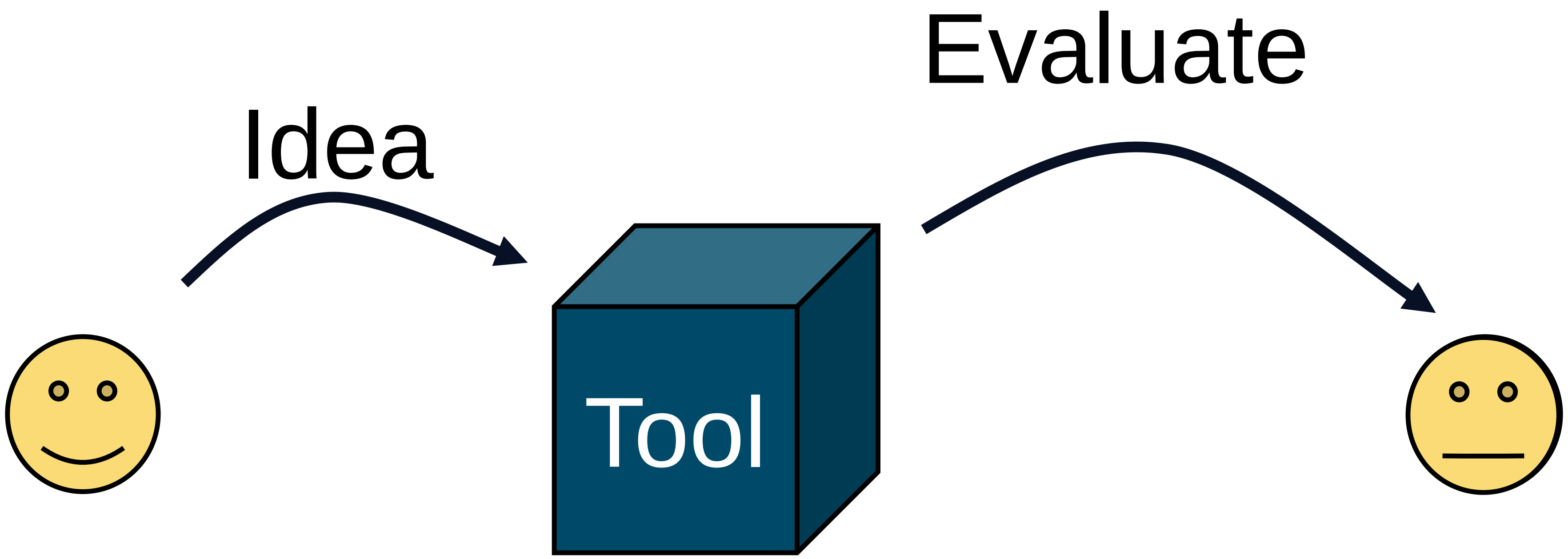

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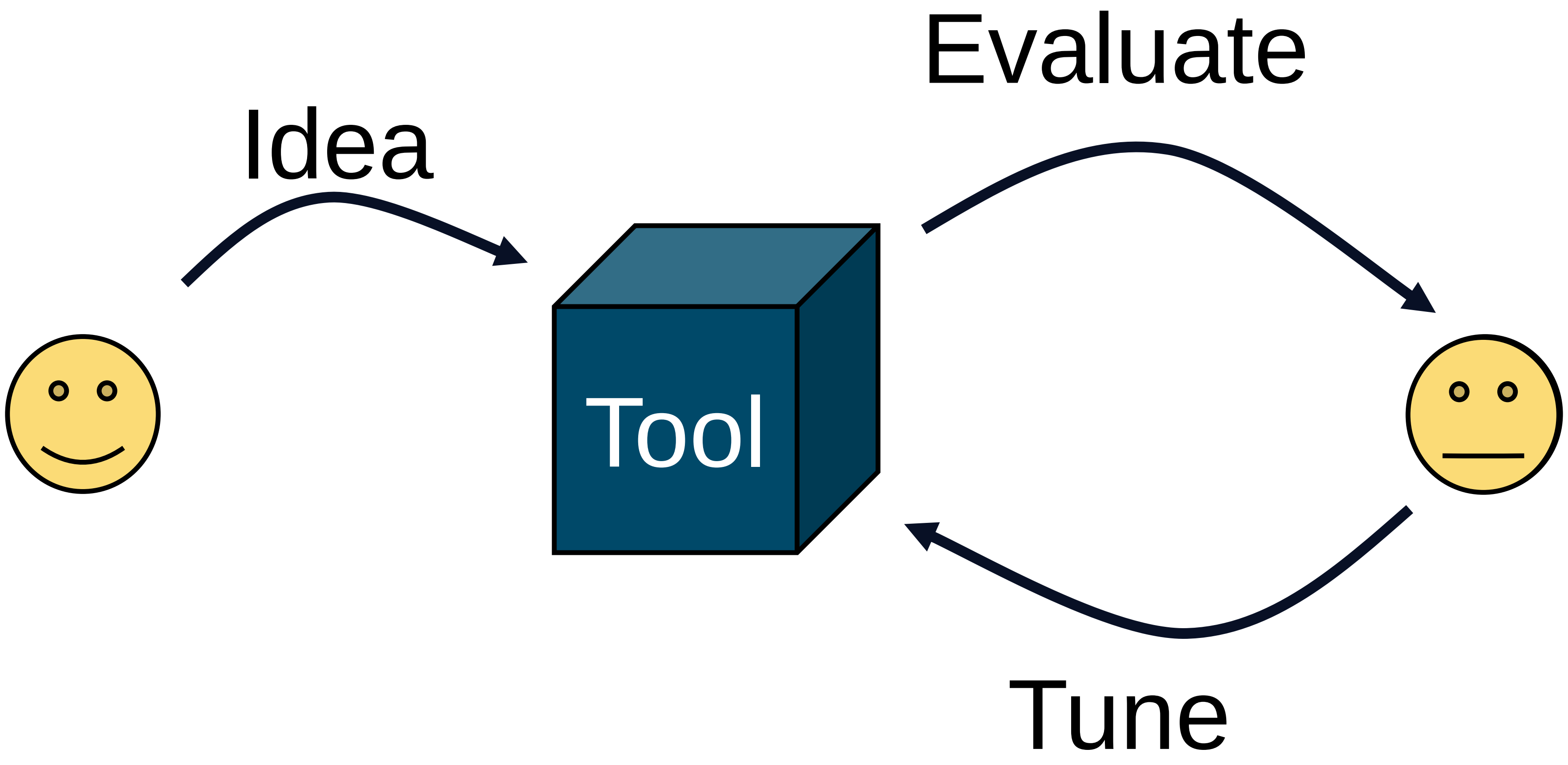

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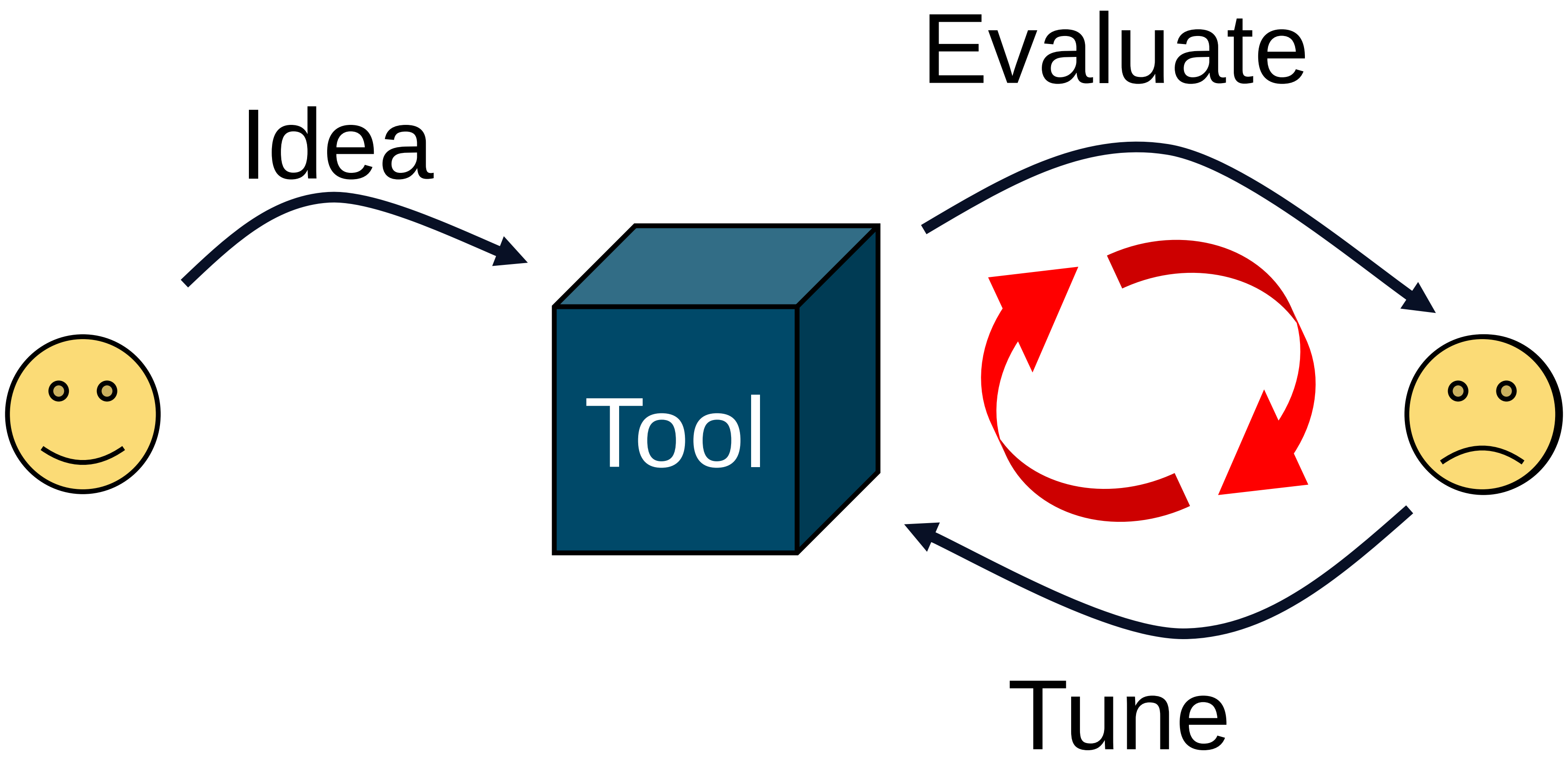

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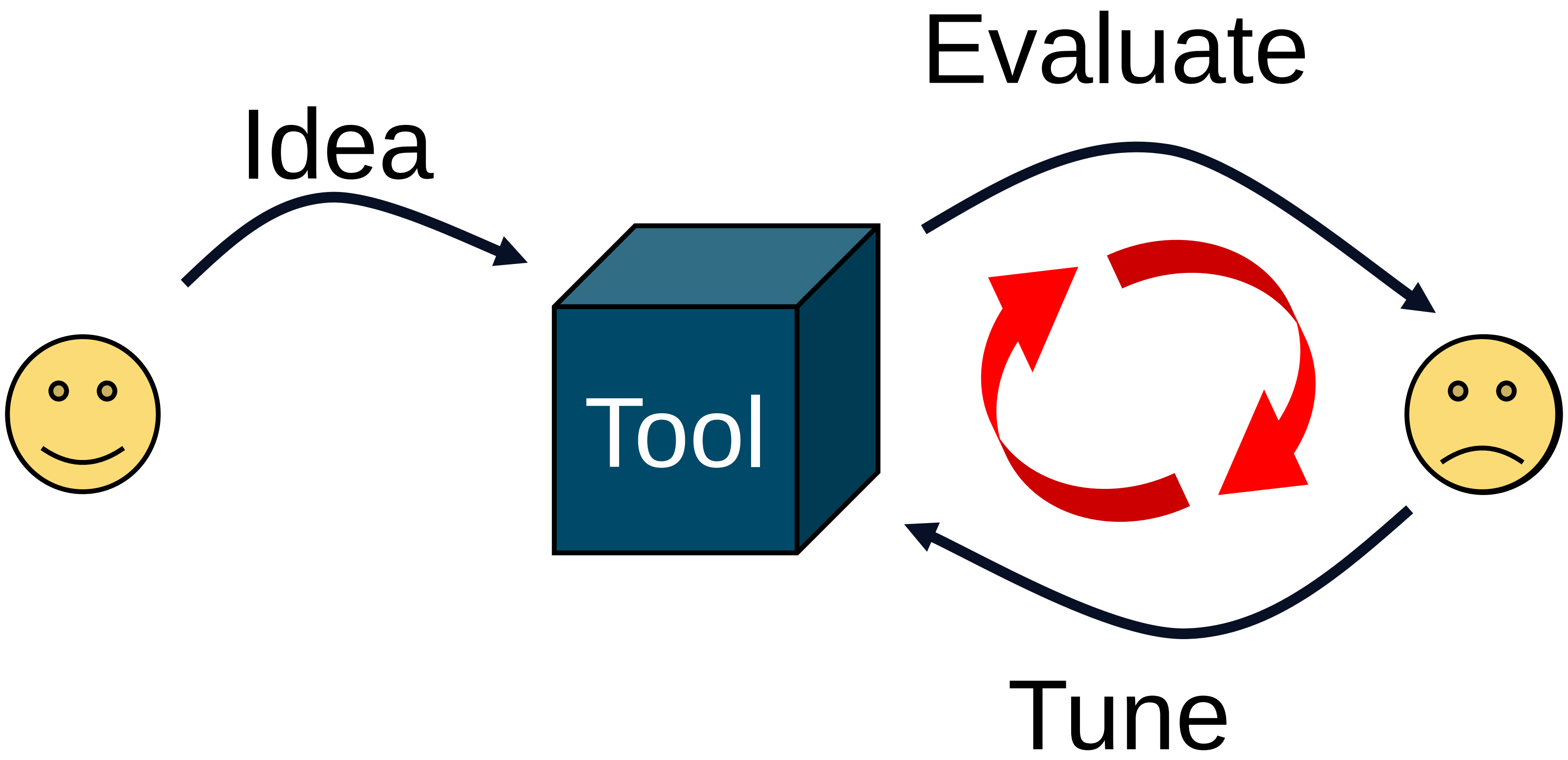
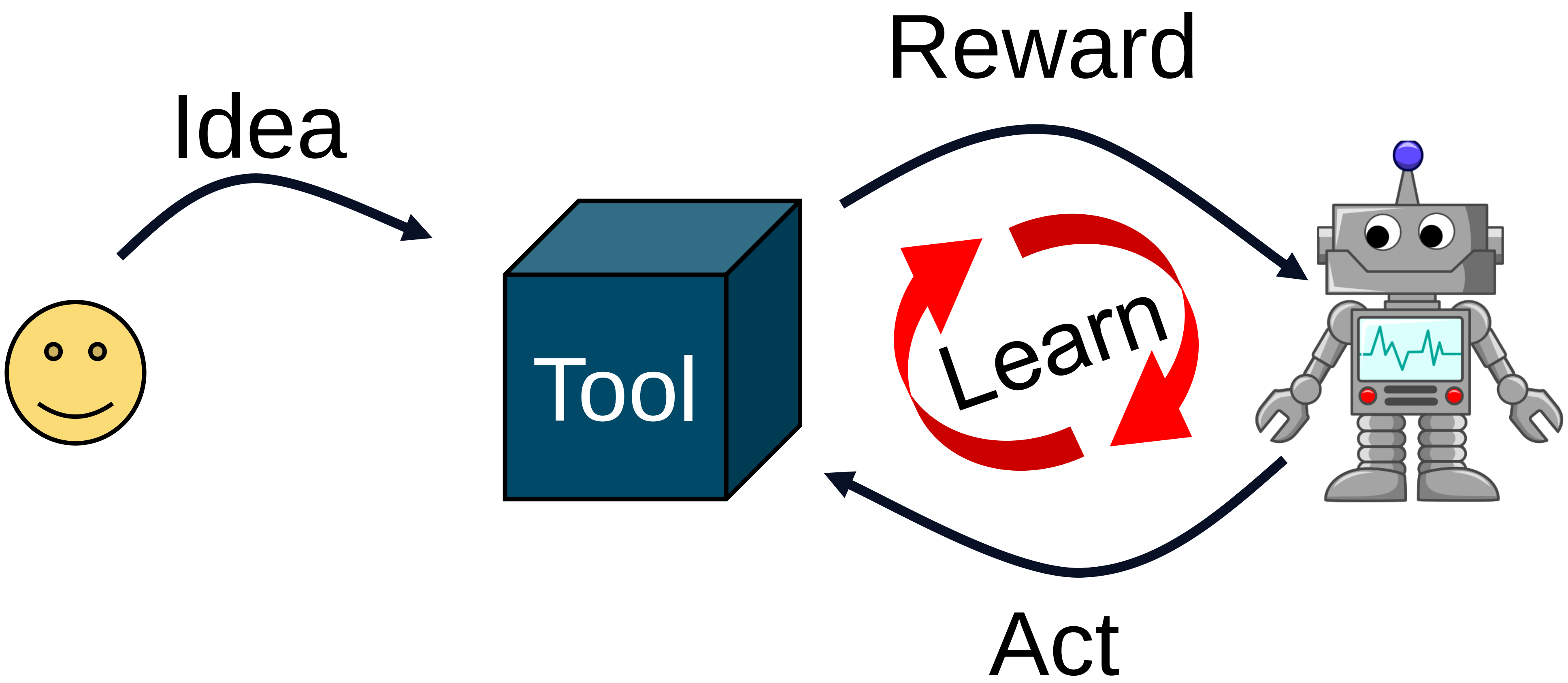


With human-in-the-loop:

- Slow
- Simple heuristics, limited tool parameters (to keep tractable)
- Tune for average case (can't investigate every benchmark design)

CAD Tool Development: Reinforcement Learning (RL)



With RL:

- Human ***out*** of the loop!
- Learn better heuristics: exploit more information, more parameters
- Online adaptation → better than average case

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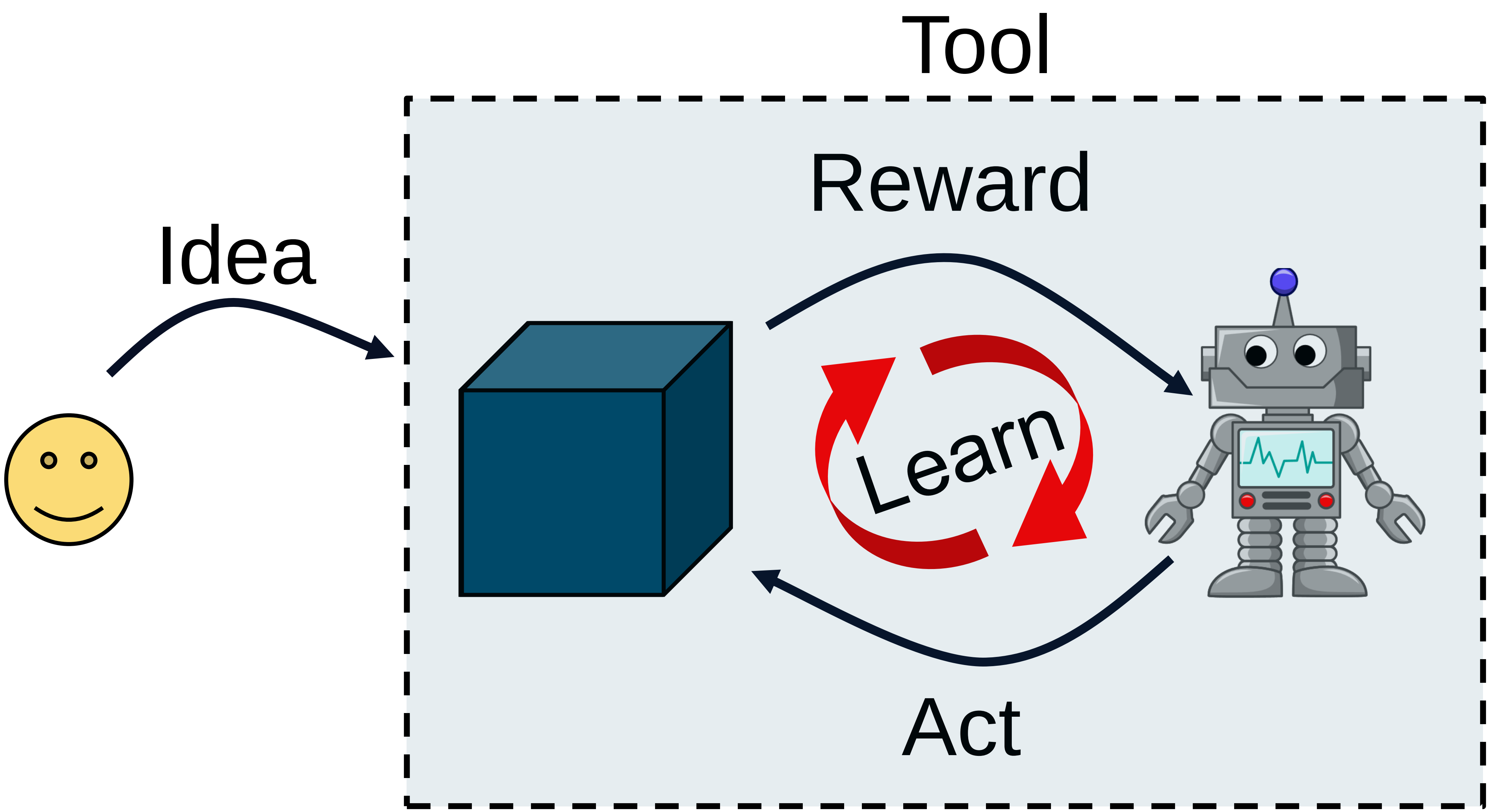

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FPGA Placement

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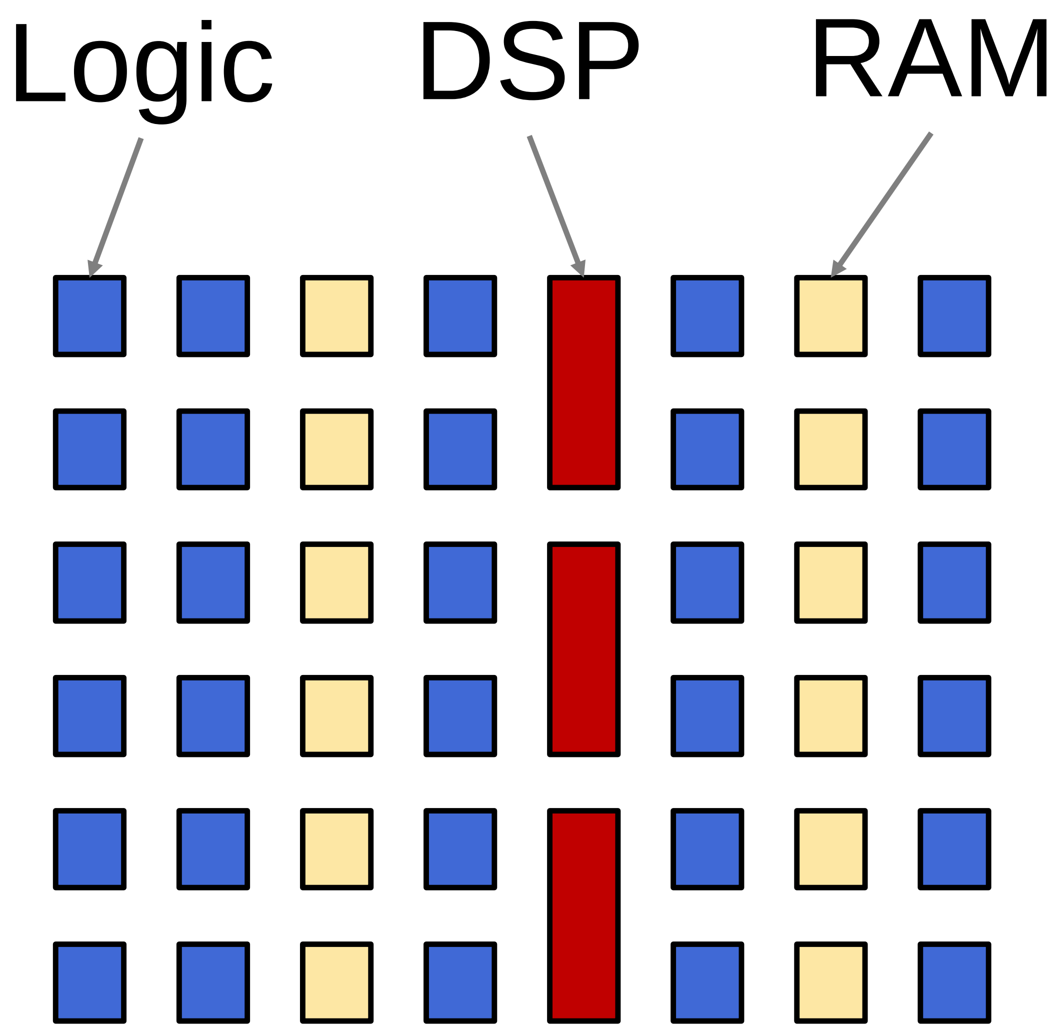


FPGA:

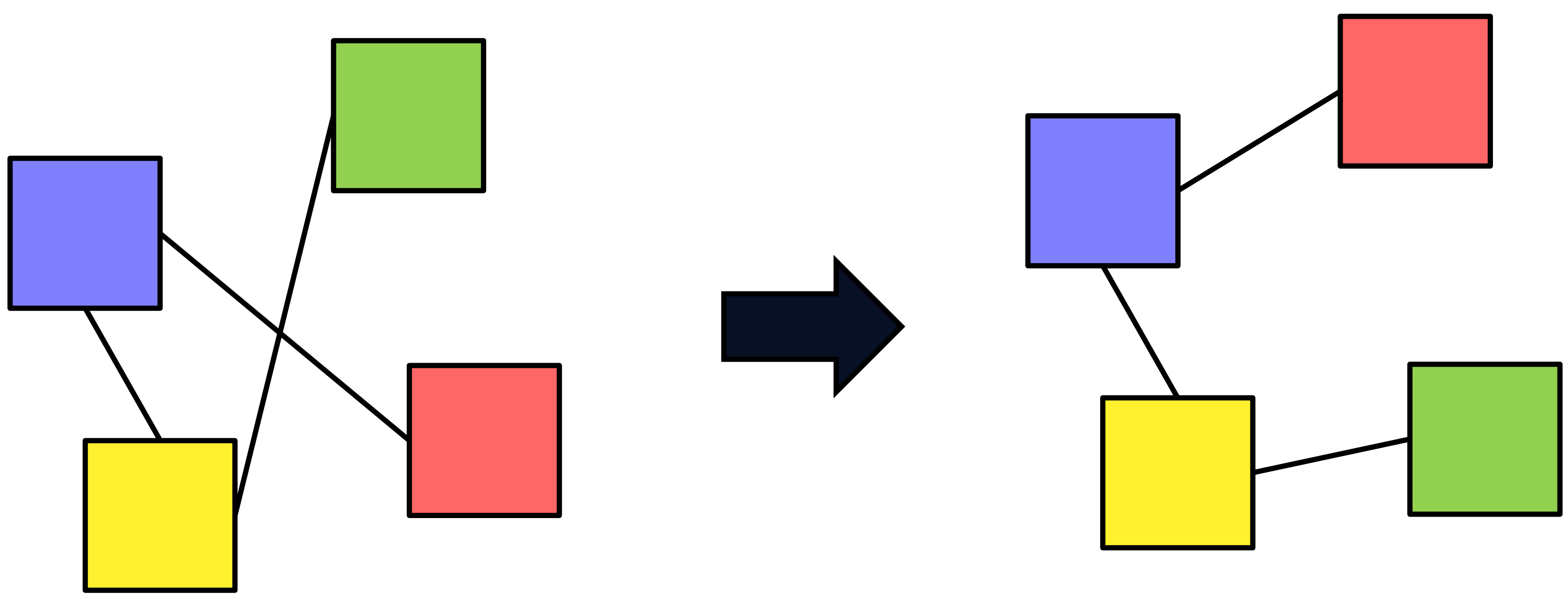
- Pre-fabricated programmable blocks and routing
- Can implement wide range of designs

Placement Considerations:

- Key step for timing (no later fix up)
  - Routing architecture dependent
- Many legality constraints
- Discrete optimization
- Large designs (millions of netlist primitives)

Simulated Annealing (SA) Placement

- Modify placement by making ‘moves’
- Accept/Reject move based on:
  - Cost change
  - Temperature (hill climbing)



Move Generation

Many possible types of moves!

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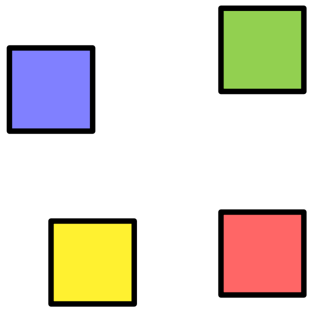

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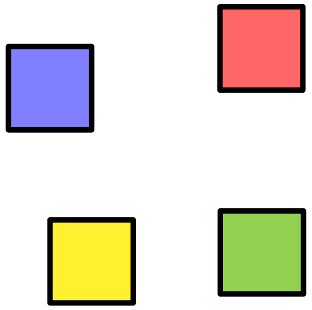

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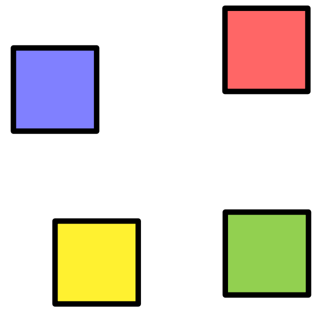

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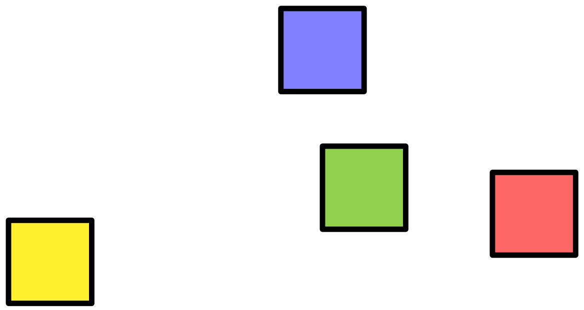

Smart: directed move to ‘good’ location (wirelength, timing)

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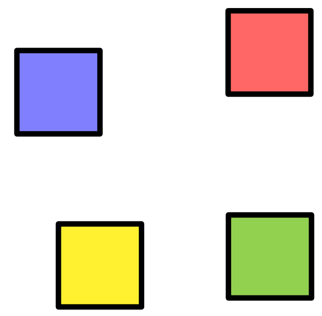

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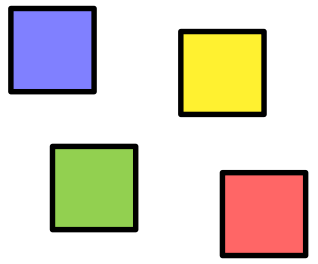

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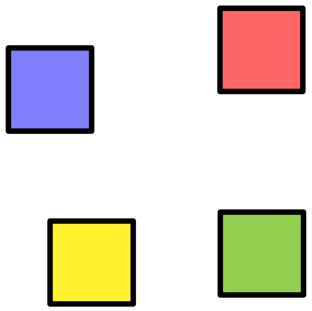

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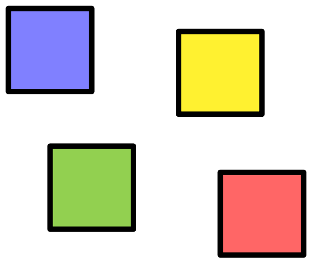

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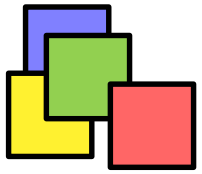

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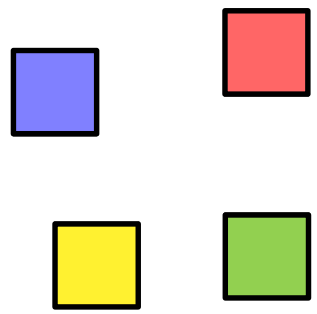

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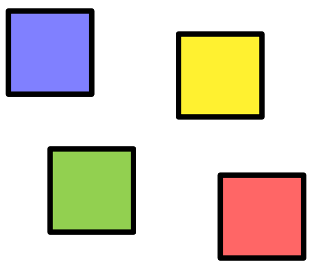

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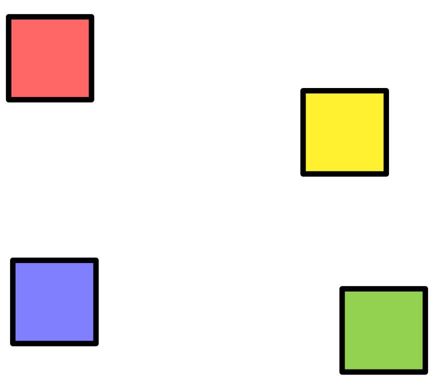

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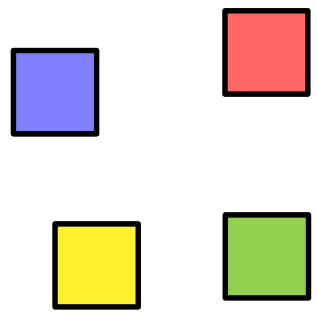

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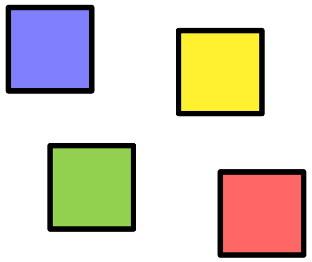

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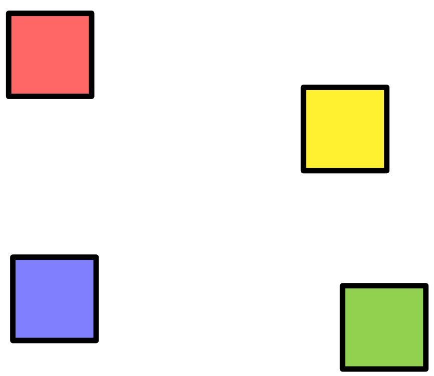

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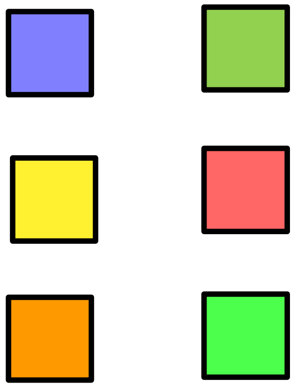

Complex: Assignment

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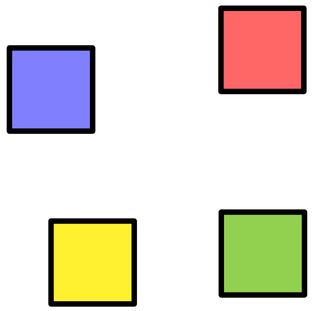

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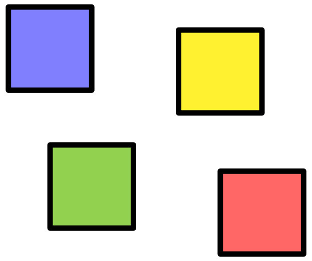

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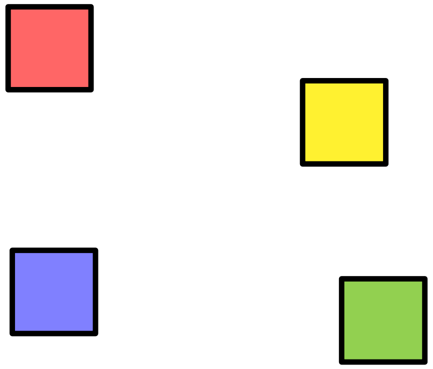

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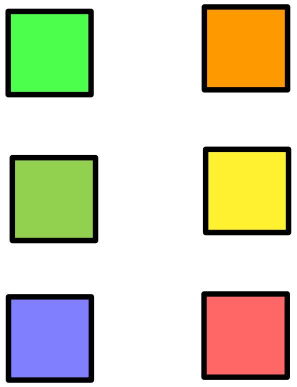

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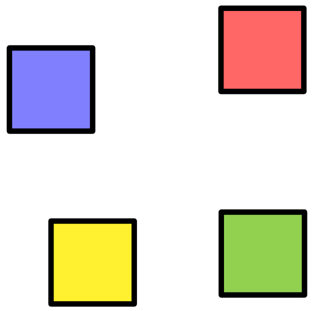

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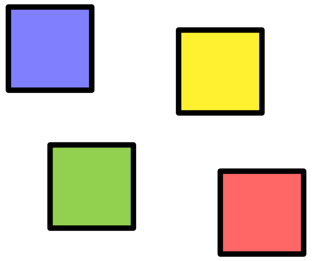

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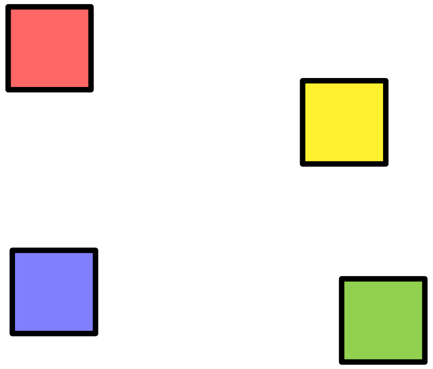

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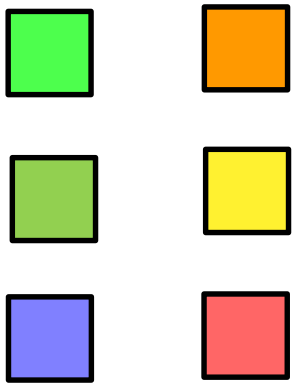

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Many considerations:

- Frequencies of different moves
- Situation dependent?
- Move ‘strength’ vs run-time

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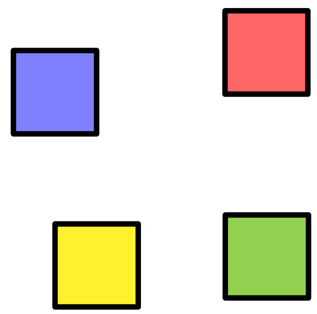

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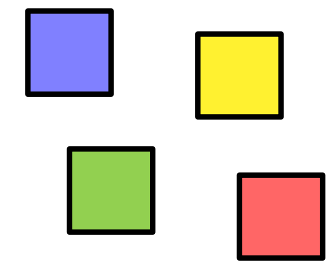

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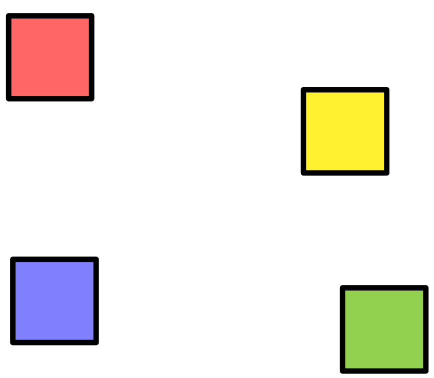

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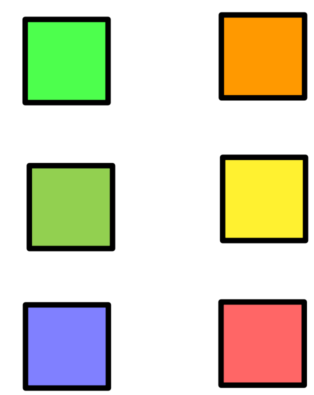

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Treat as RL Problem!

RL Move Generator

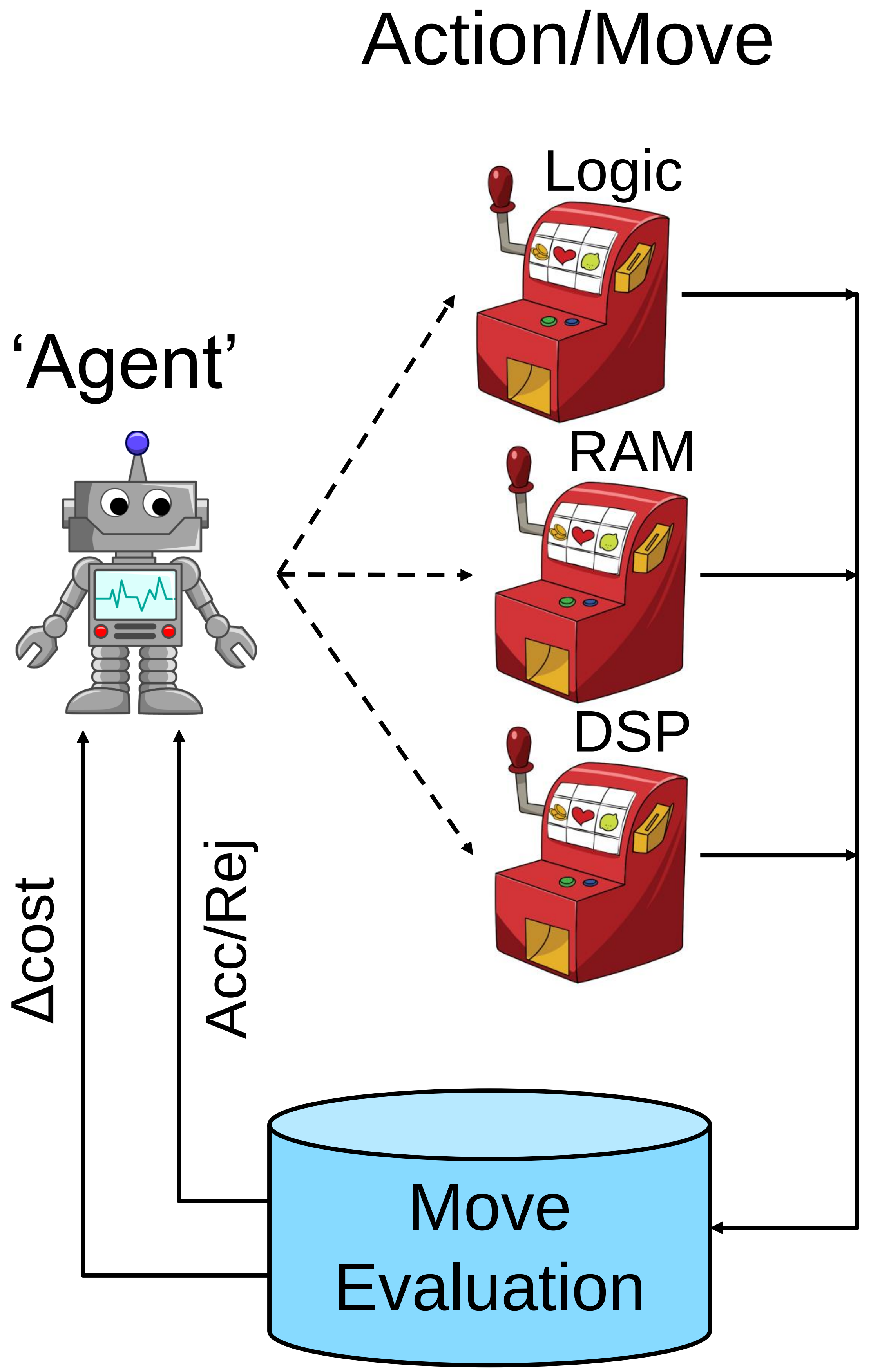
Actions: moved different block types

Reward:

- Accepted: -Δcost
- Rejected: 0

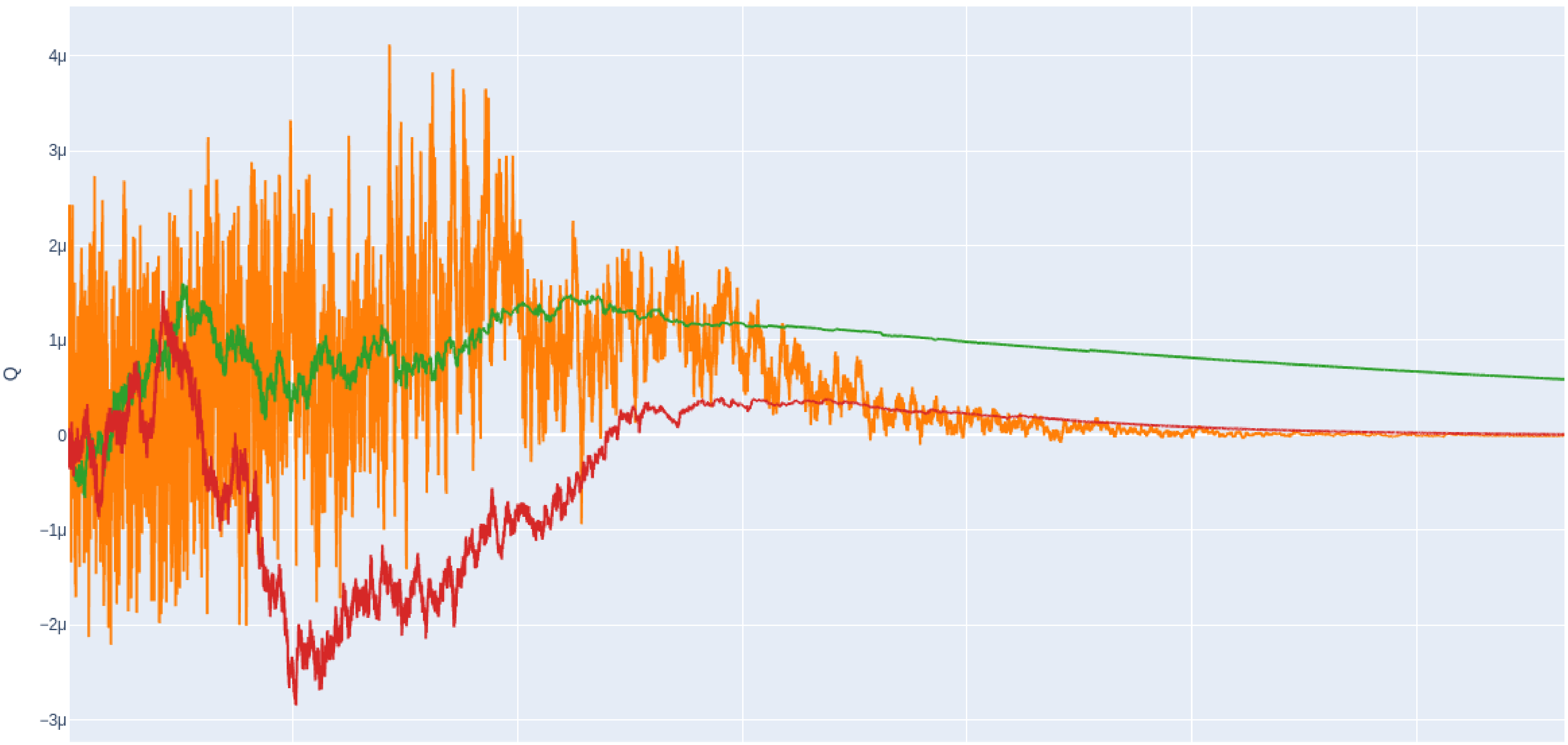
Agent:

- Estimates value of actions
- Selects action to take



Estimating Action Values

- Values of action are not stationary!



Move

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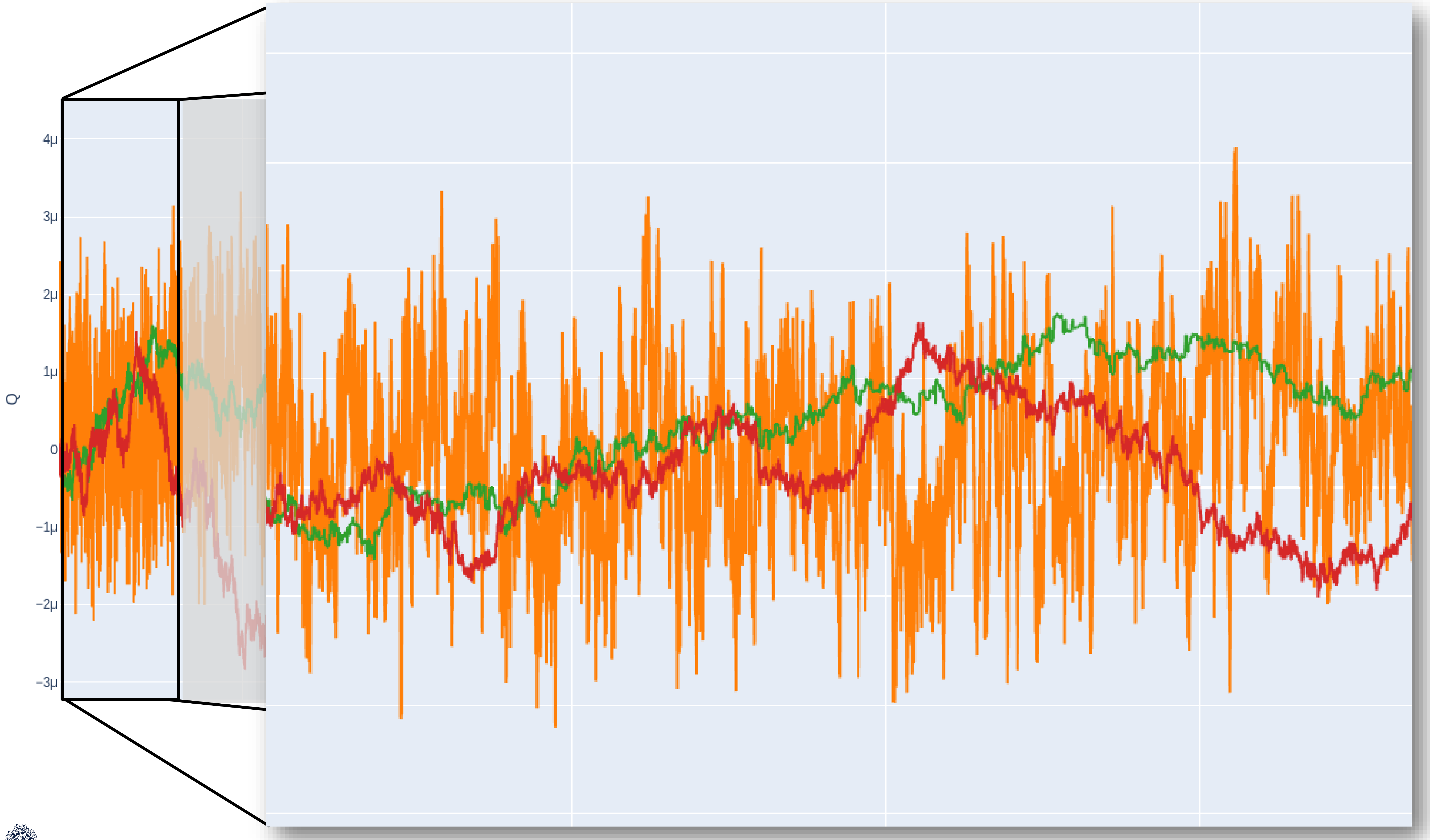

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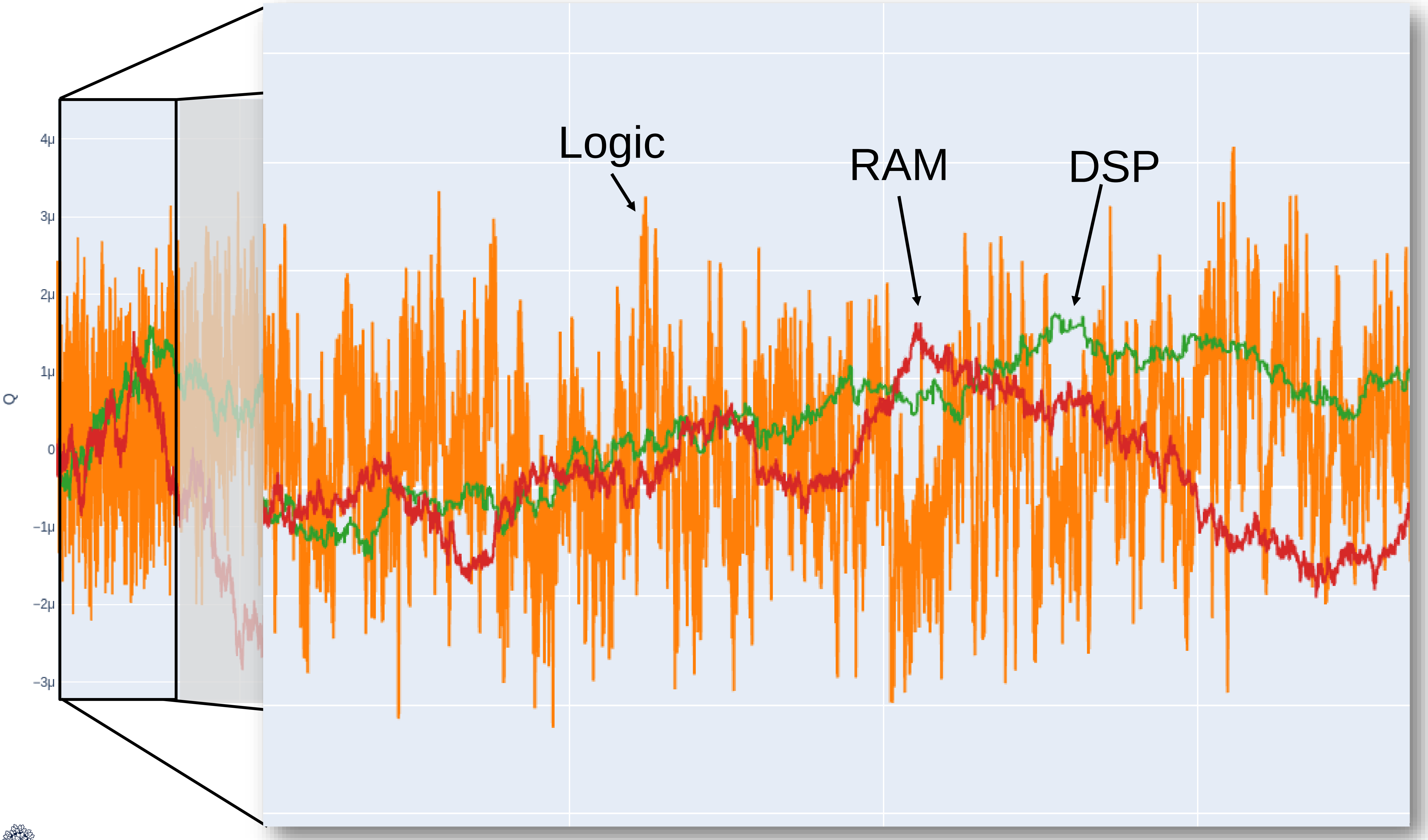

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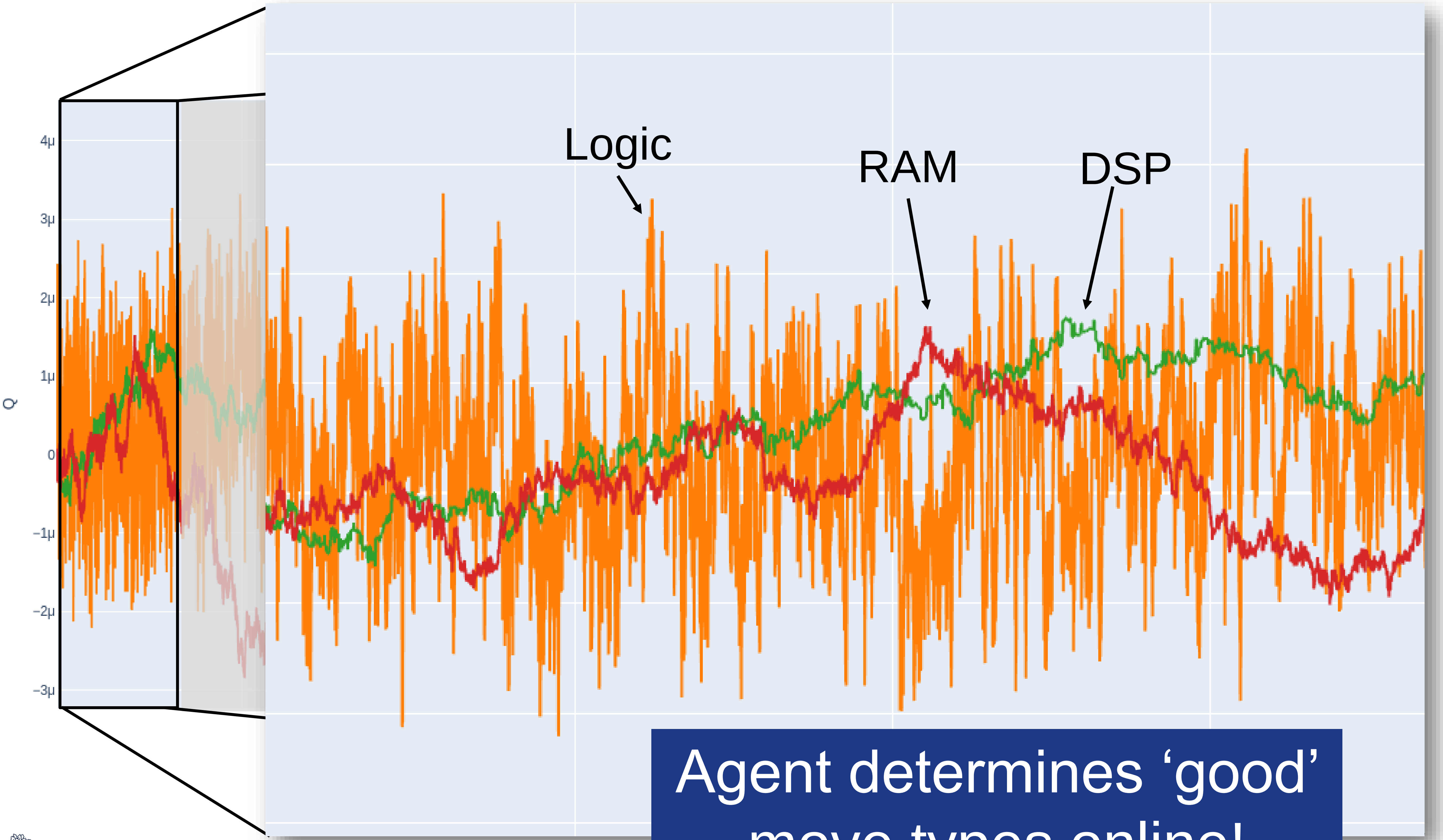
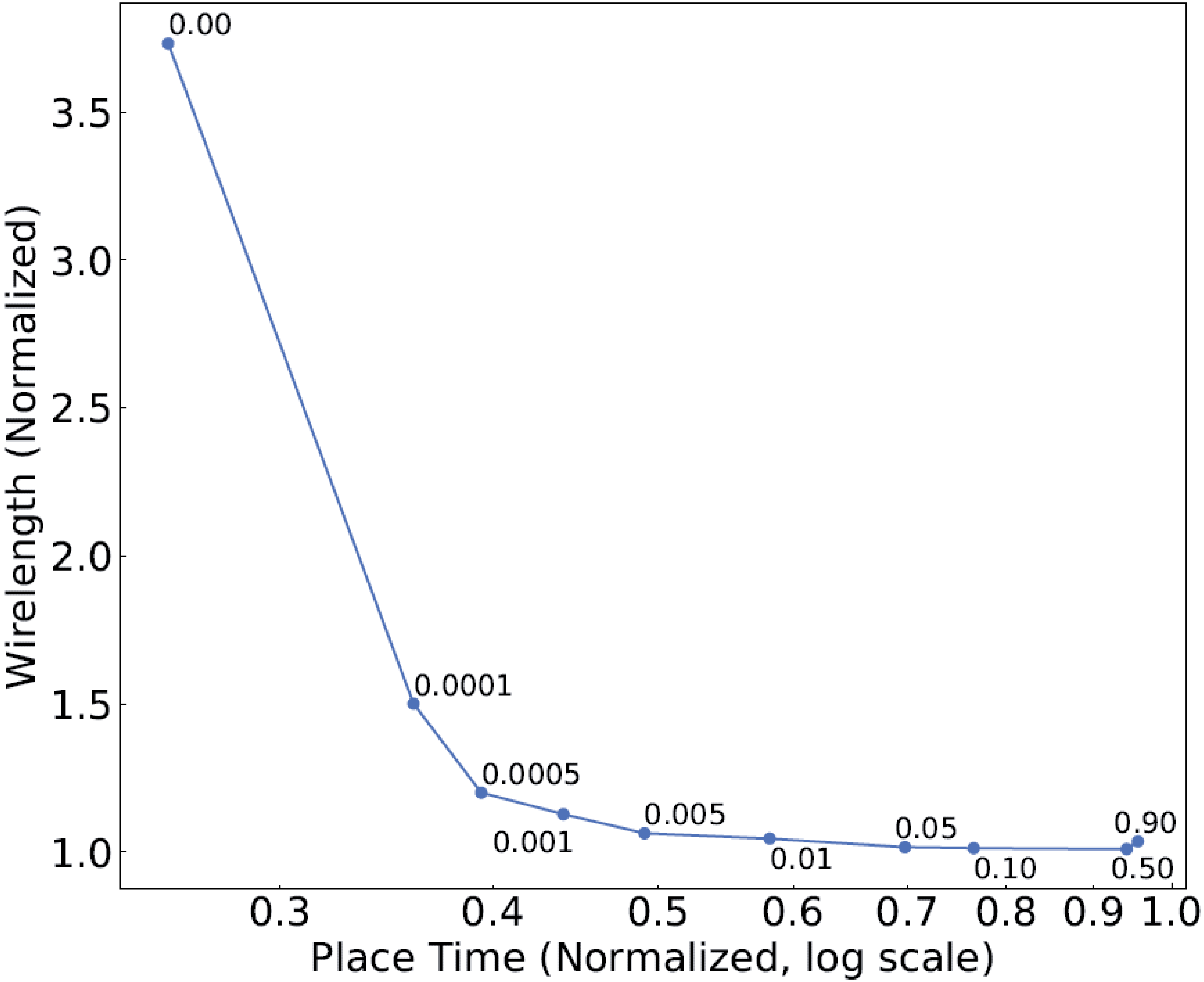


Agent determines ‘good’ move types online!

Action Selection: Exploration vs Exploitation

- ε-greedy: Mostly greedy (exploit), occasionally random (explore)
  - ε: fraction of exploratory moves



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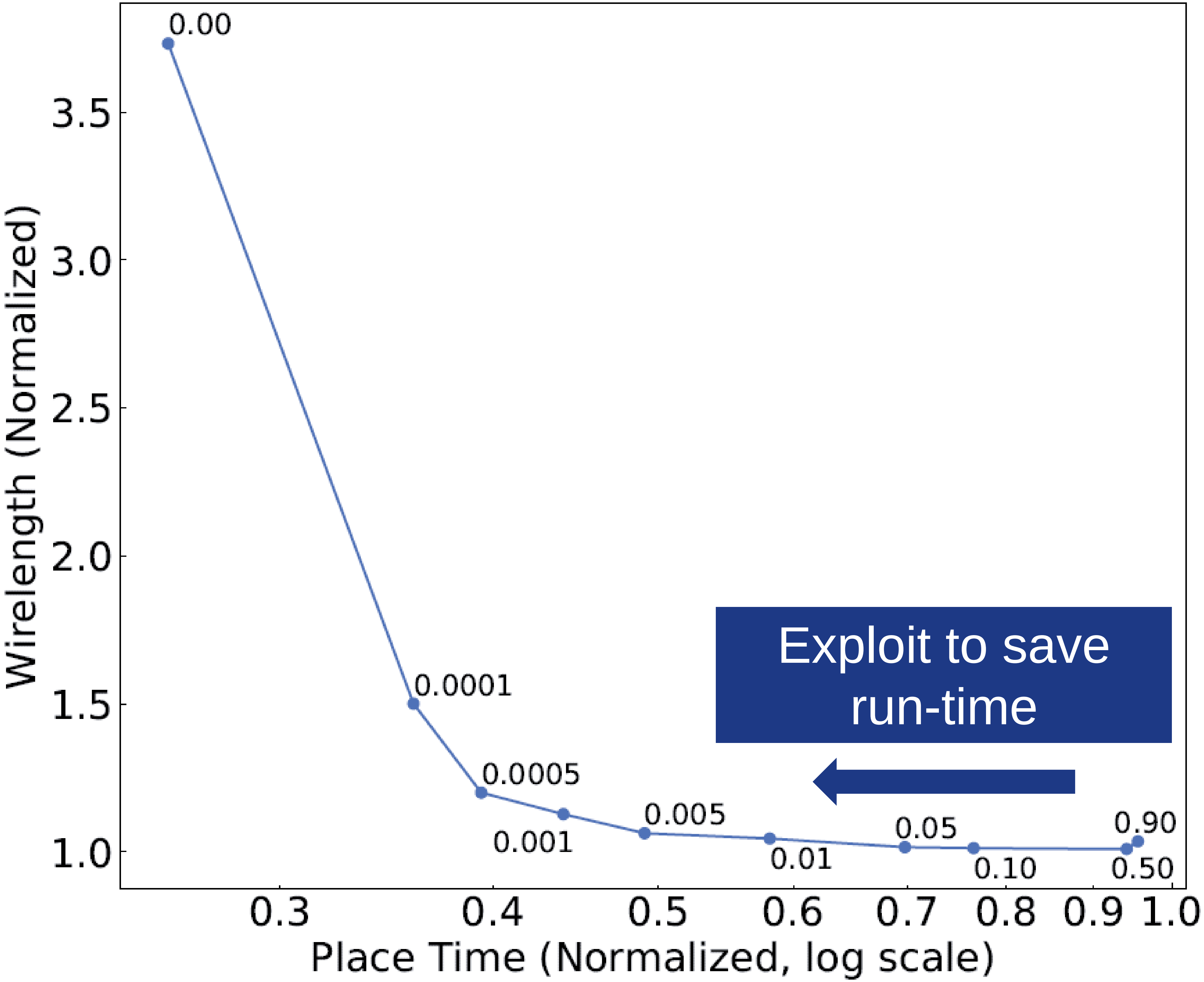

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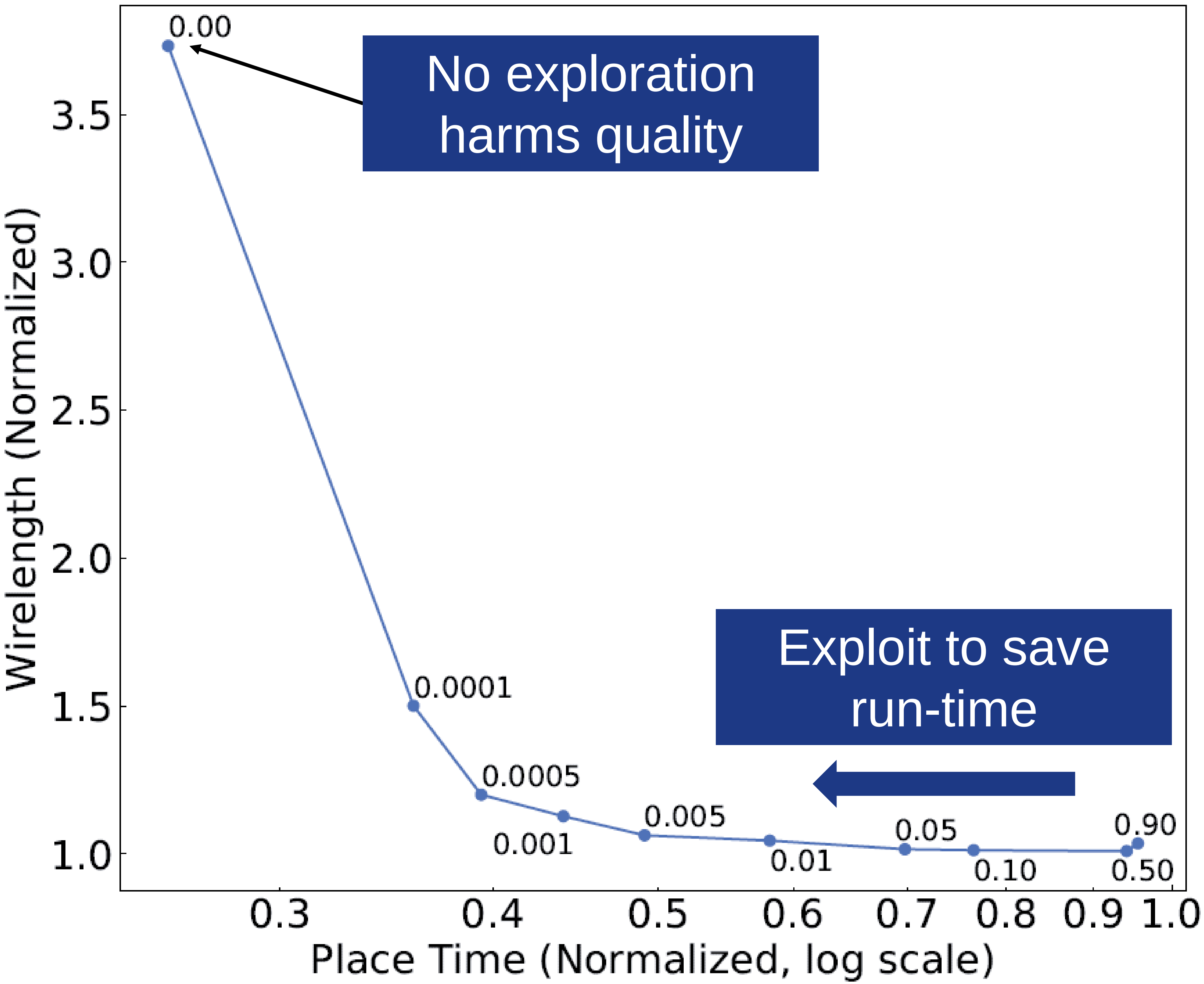
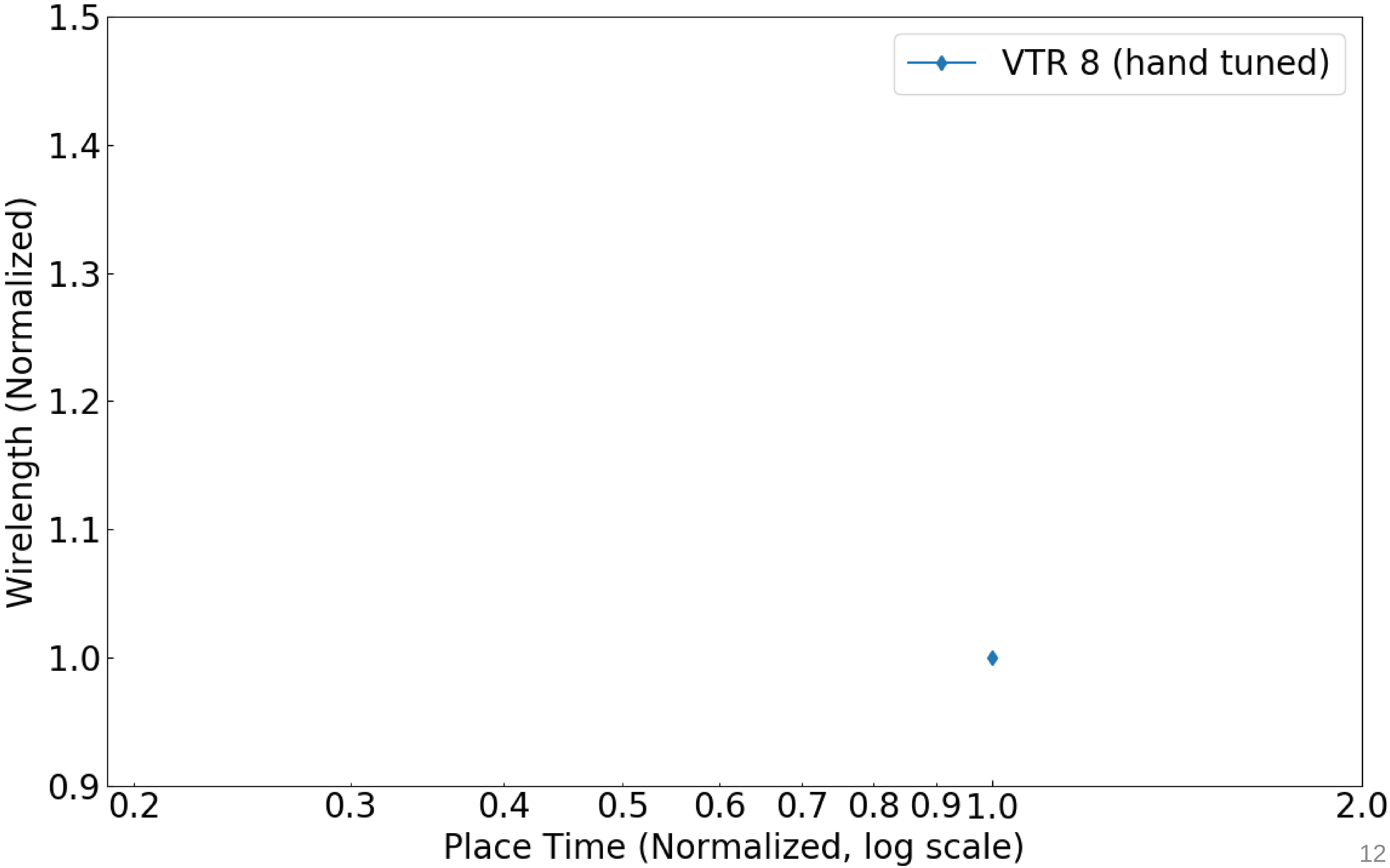


Quality/Run-time Comparison

- VTR Benchmarks (10K-165K primitives), 3 seeds



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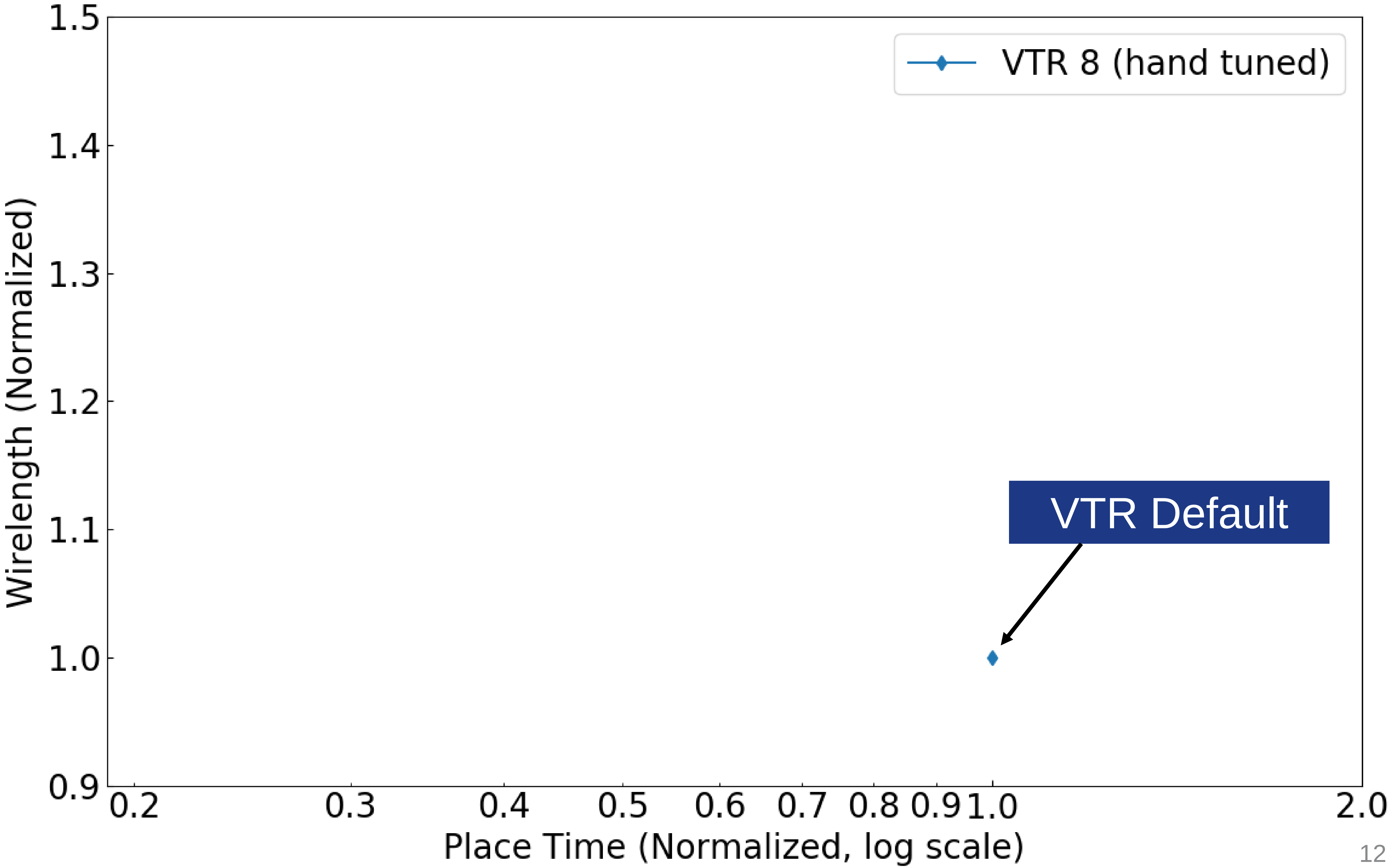

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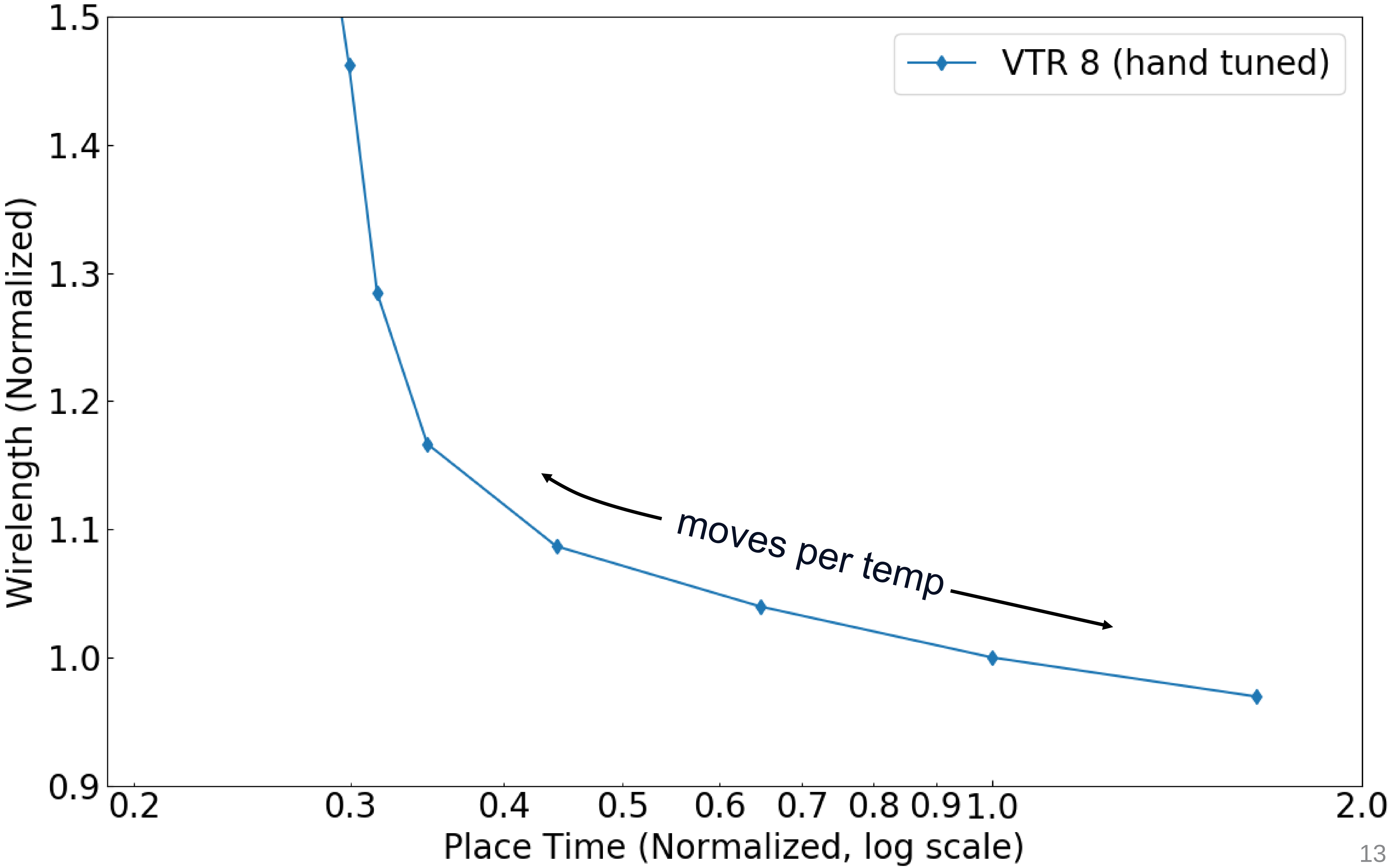

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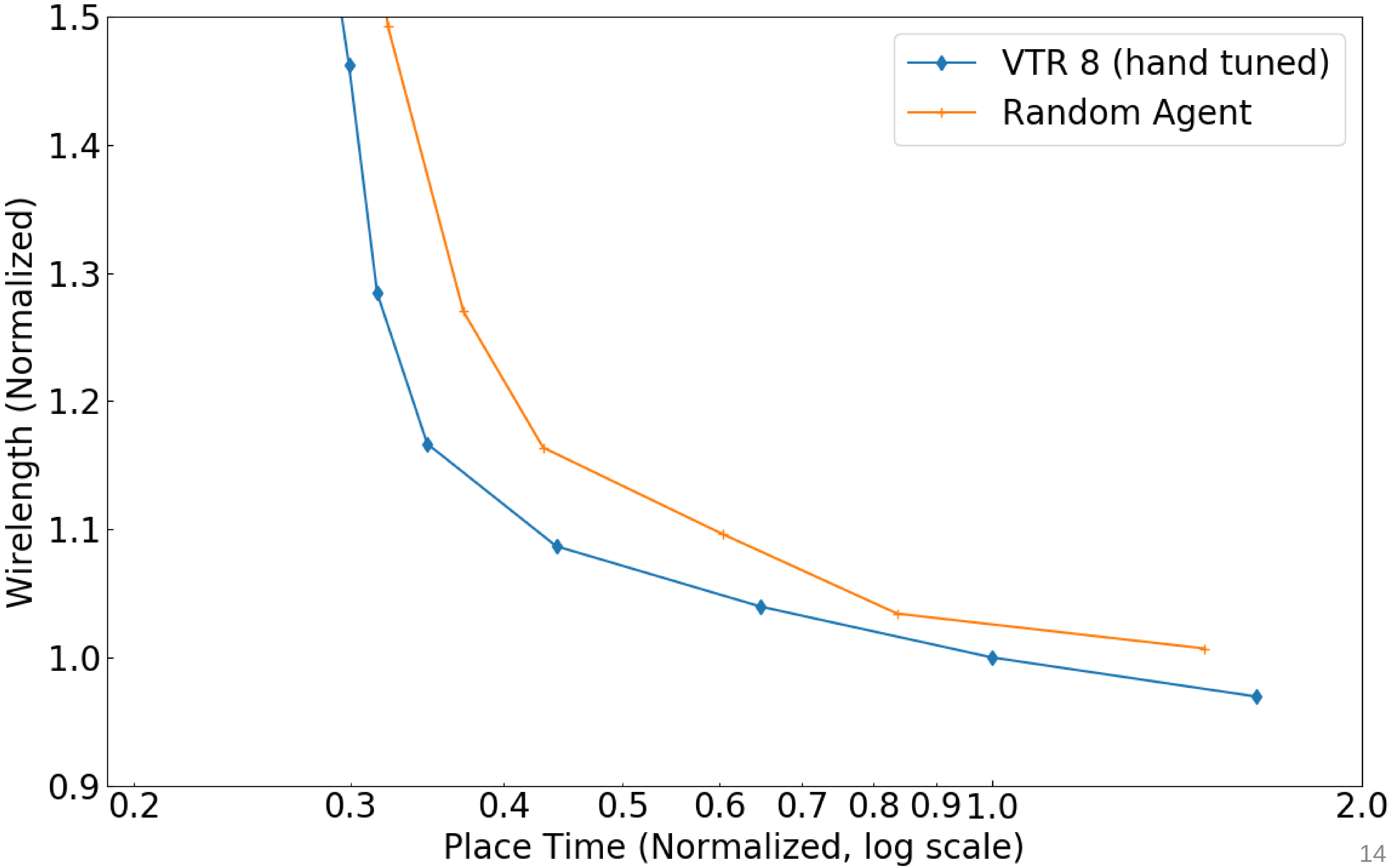

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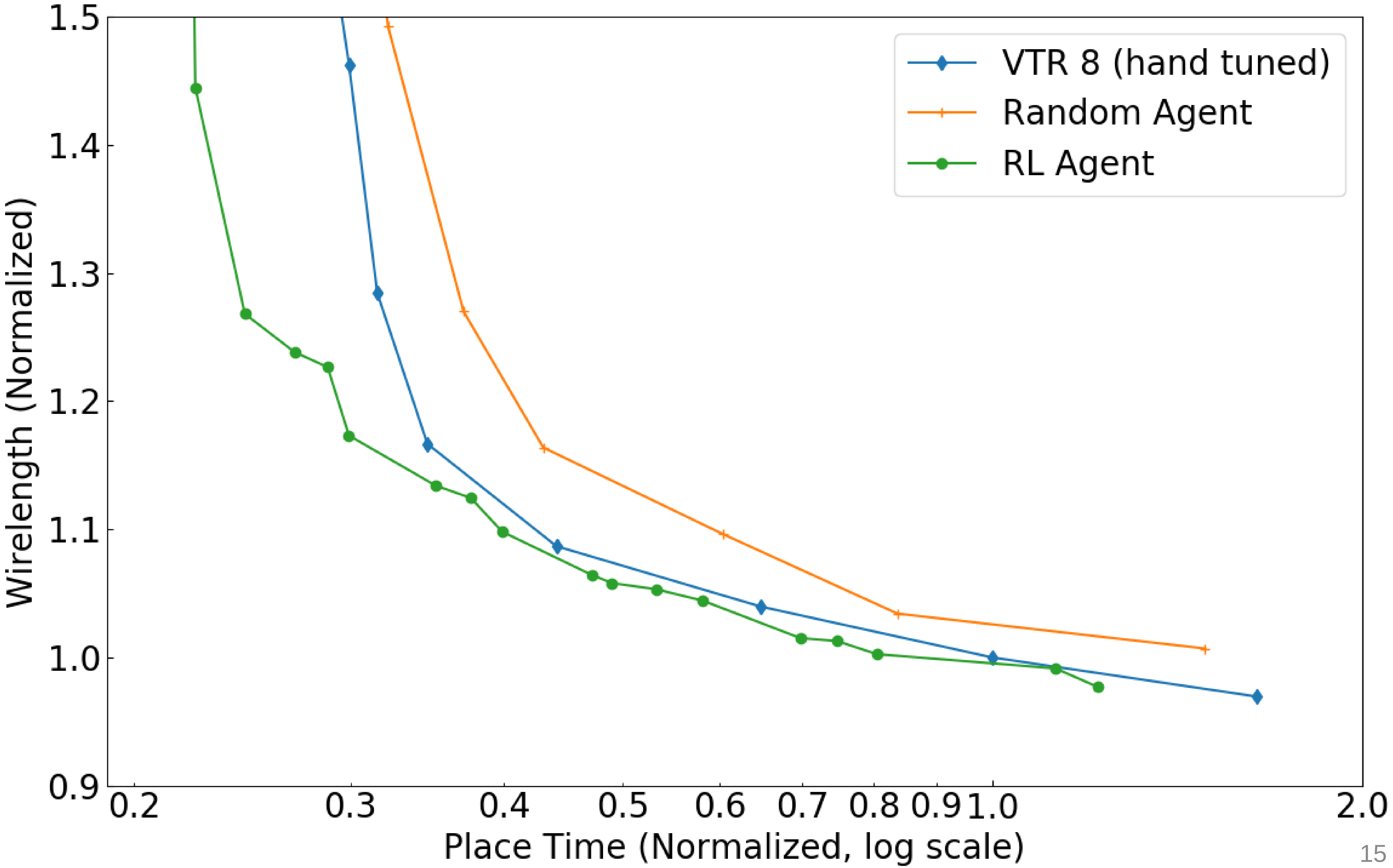

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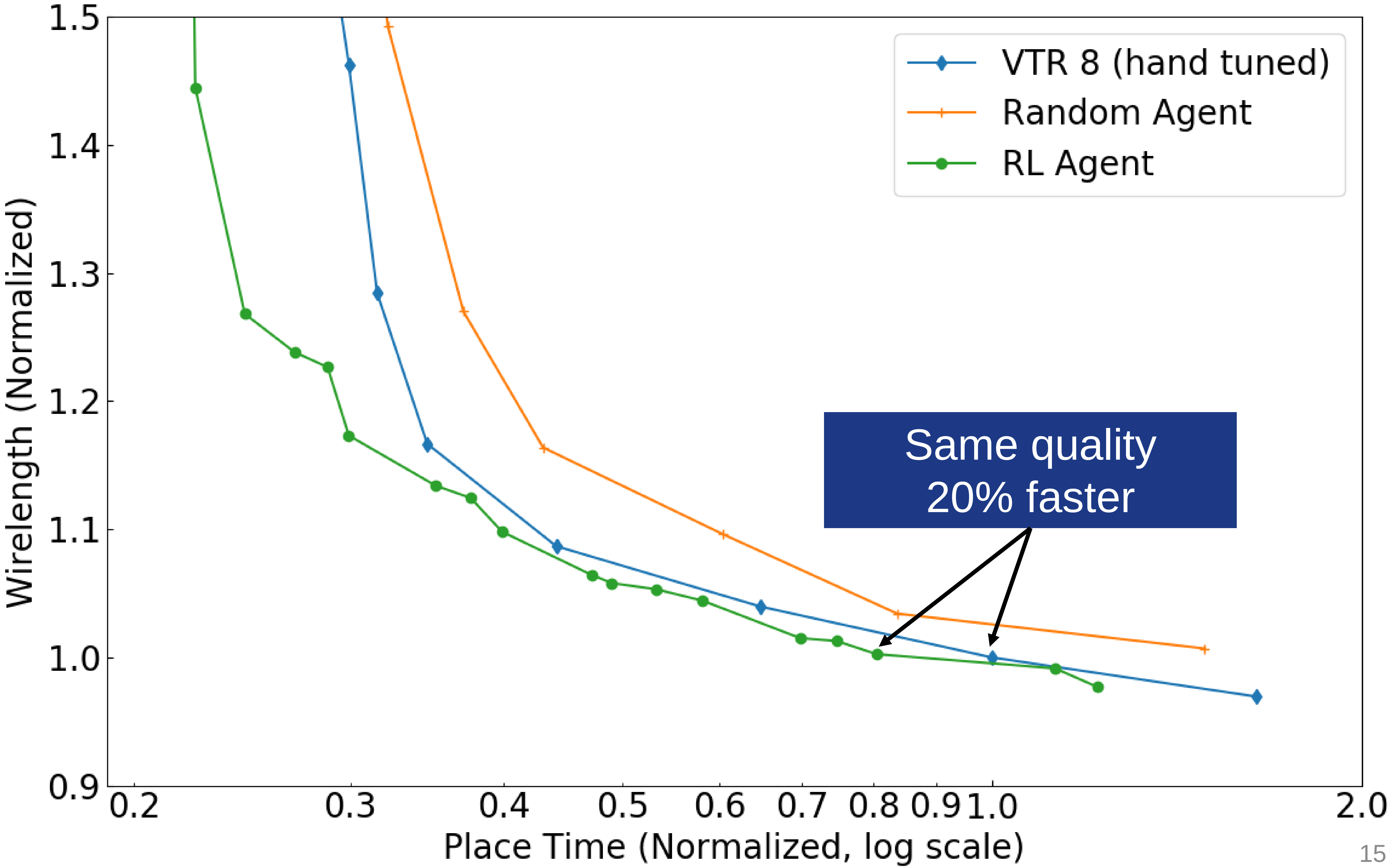

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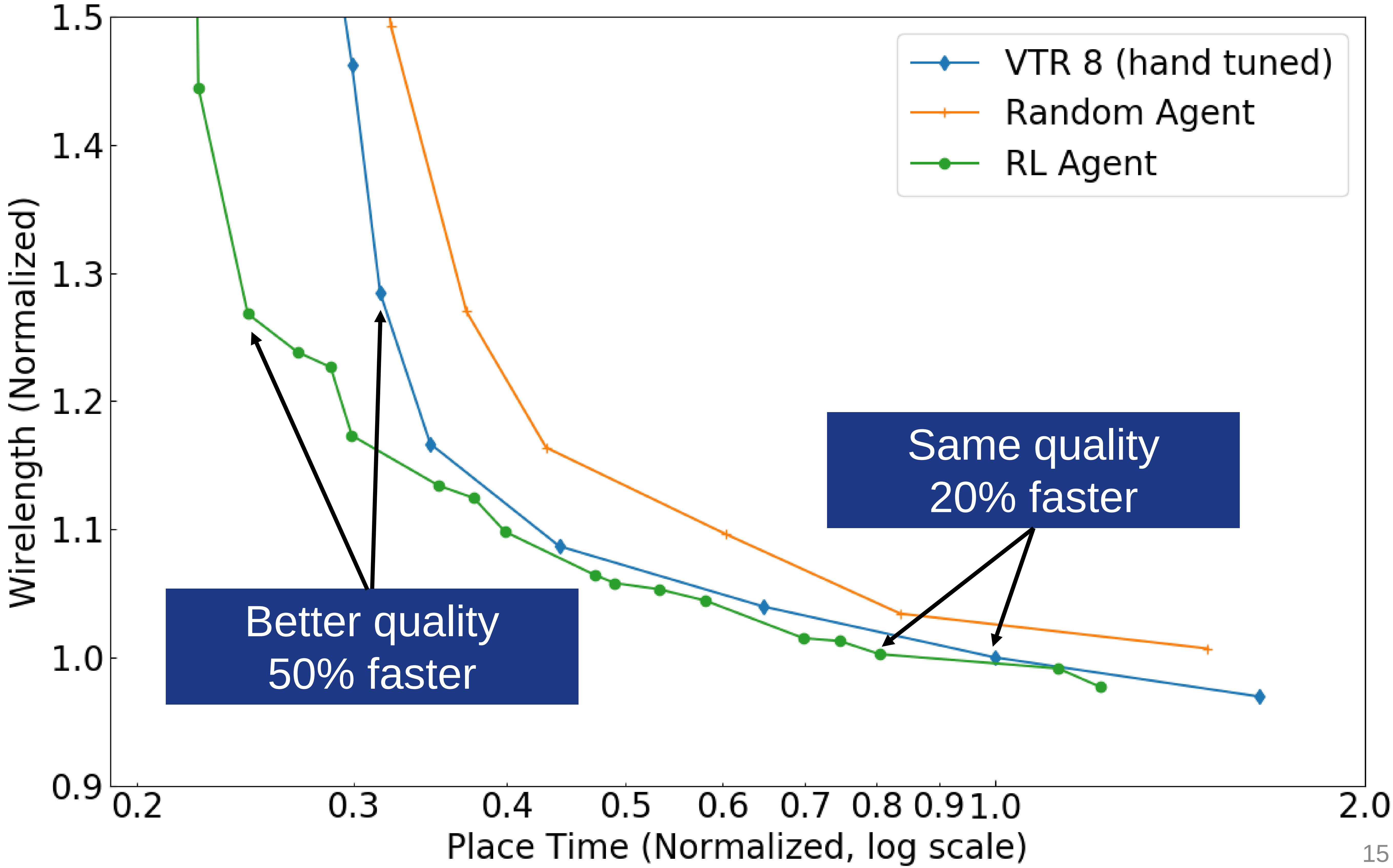


Conclusion

- RL-enhanced Simulated Annealing based FPGA Placer
  - RL agent controlled move generator
  - Learns on-line what types of moves are productive
  - Improves run-time/quality trade-offs
    - *Particularly at low run-times*

Future Work

- More types of moves
- Other reward formulations (e.g. cost run-time)?
- Agent:
  - Less greedy action selection (soft-max)?
  - Use more state information: Circuit & Optimizer statistics
- Learn:
  - Off-line agent training
  - Other RL algorithms (e.g. Temporal Difference Learning, Policy Gradients)
- Explore RL elsewhere in CAD flow

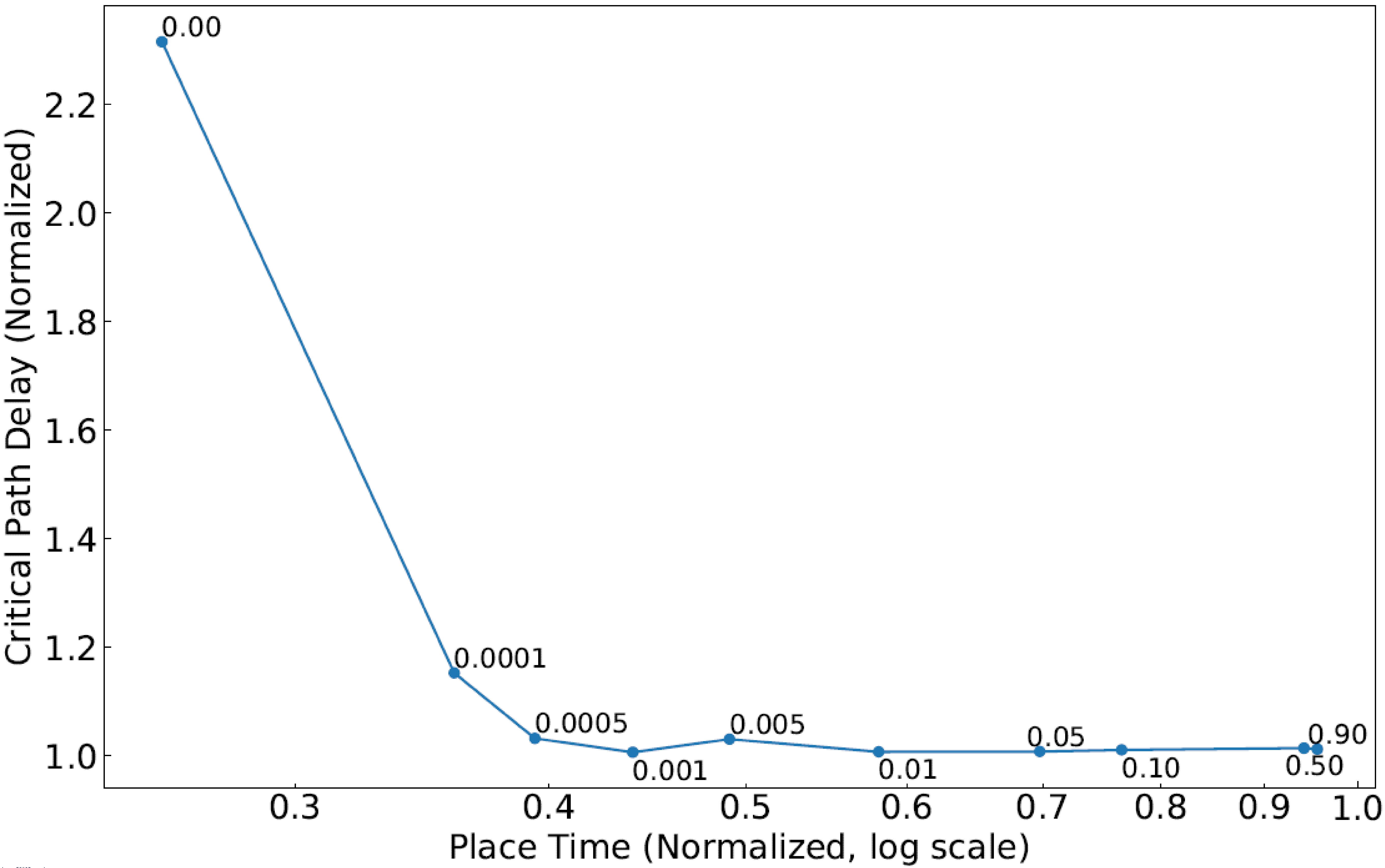
Thanks!

Questions?

Email: kmurray@eecg.utoronto.ca

Backup

Exploration vs Exploitation: Critical Path Delay



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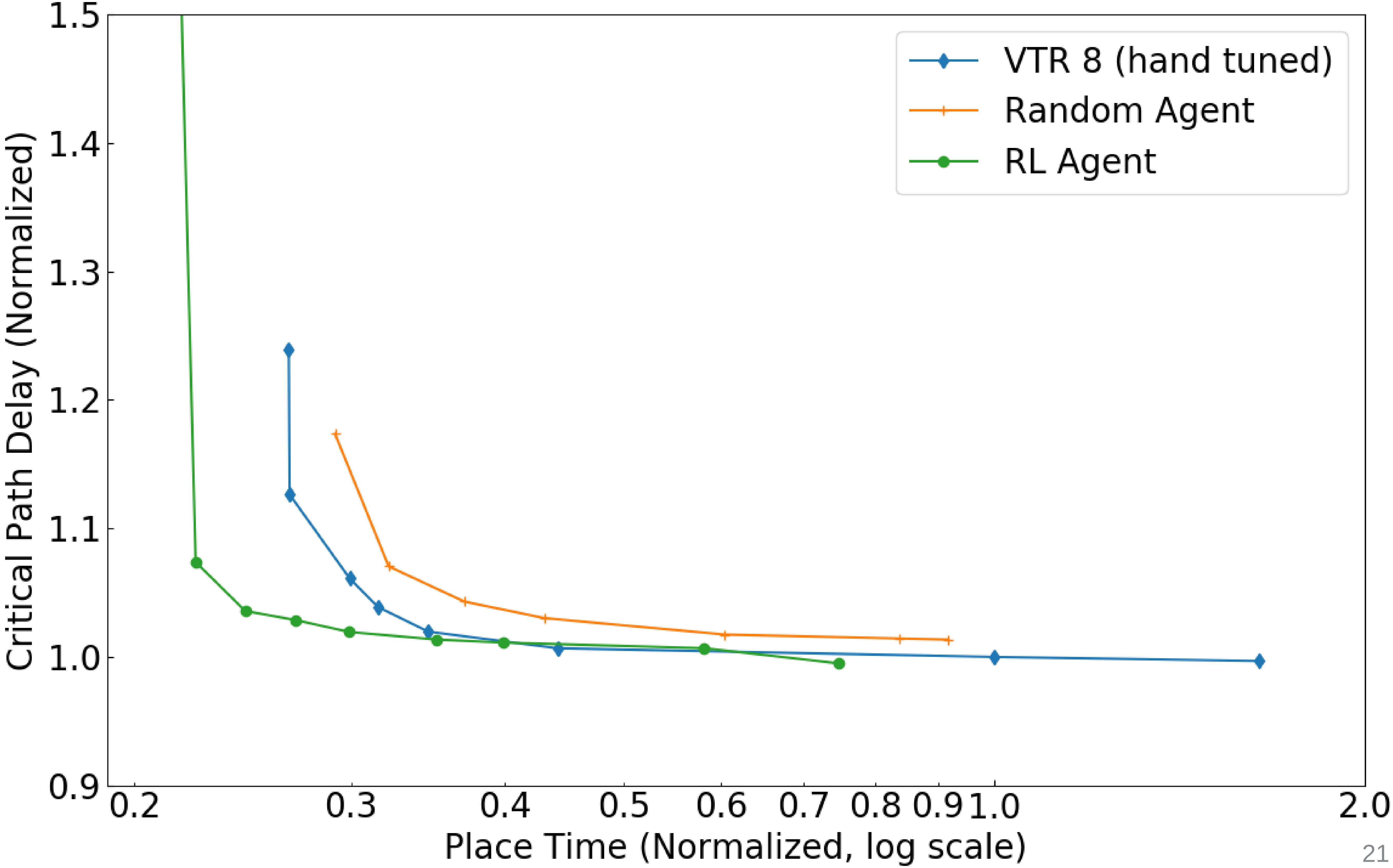
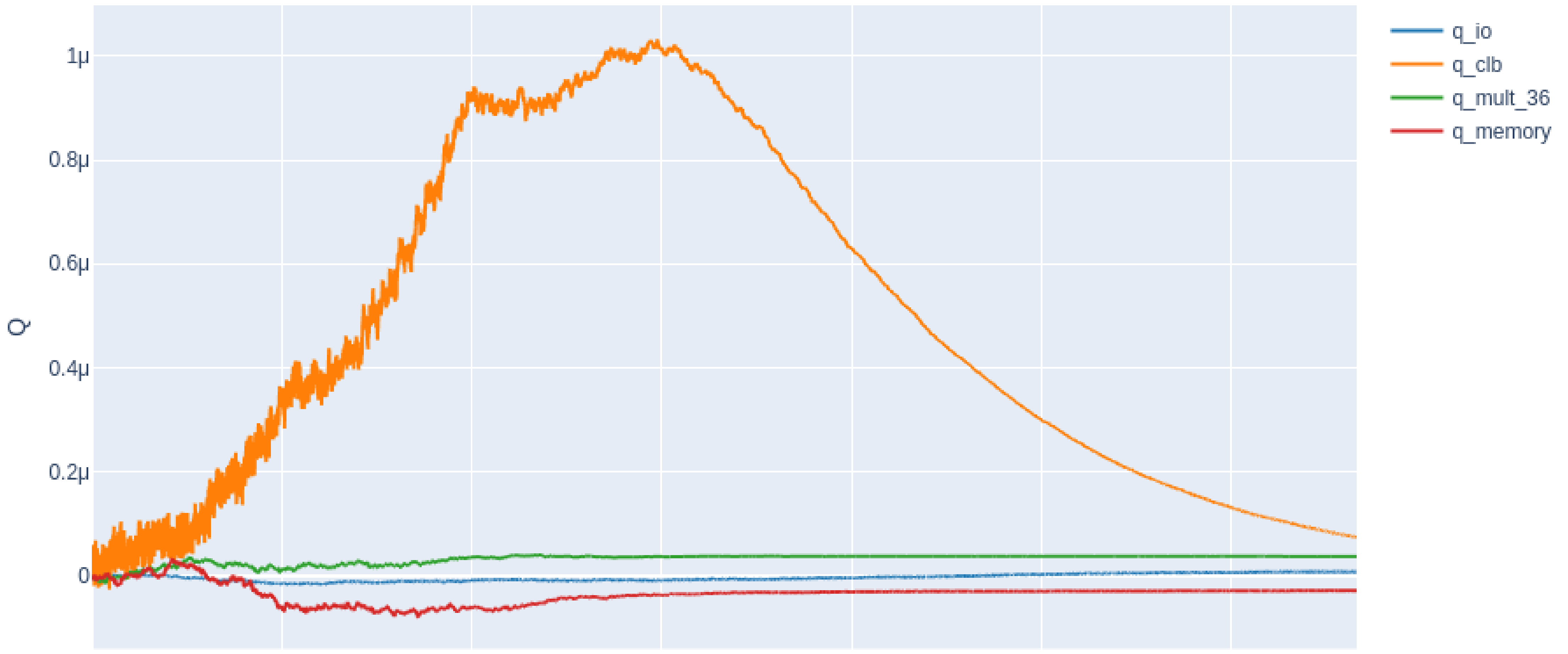
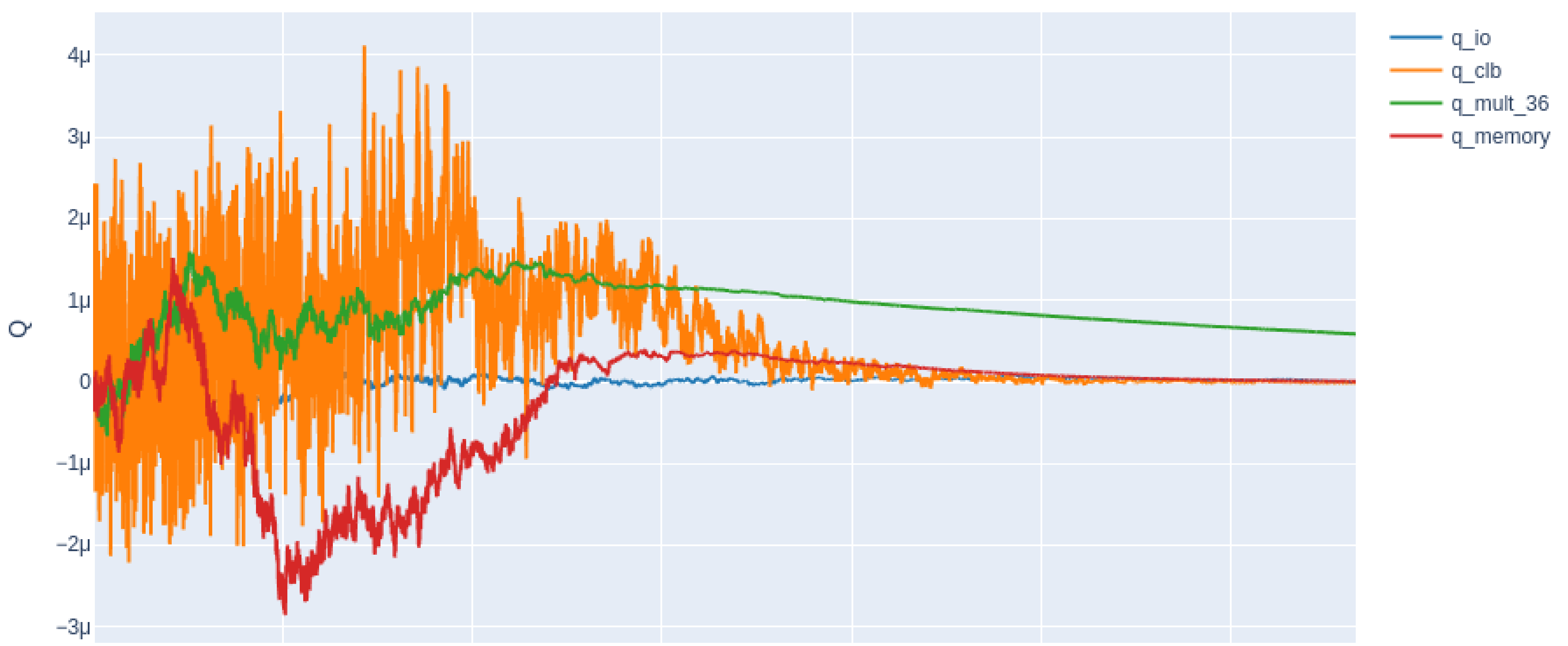


Estimating Action Values: Time Scale

Long Time-scale



Short Time-scale



Reinforcement Learning (RL) for CAD: Challenges

Long CAD Run-times

- Must exploit limited experience

Long delayed rewards

- Core challenge of RL
- CAD has well defined objectives

Nested black-box optimization

- CAD optimization already difficult to interpret/debug
- Nested optimization makes interpretability more challenging