Scheduling Live Interactive Narratives with Mixed-Integer Linear Programming

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Outline

- Live interactive narratives
- Describe our problem formulation
- Live Interactive Narrative Scheduler
- Evaluate scalability and feasibility

Live Interactive Narratives (LINs)

multiple players participate in a **predesigned narrative** taking on **fictional roles** and **interacting with real world objects and actors**

Bad News

45 min
narrative arc

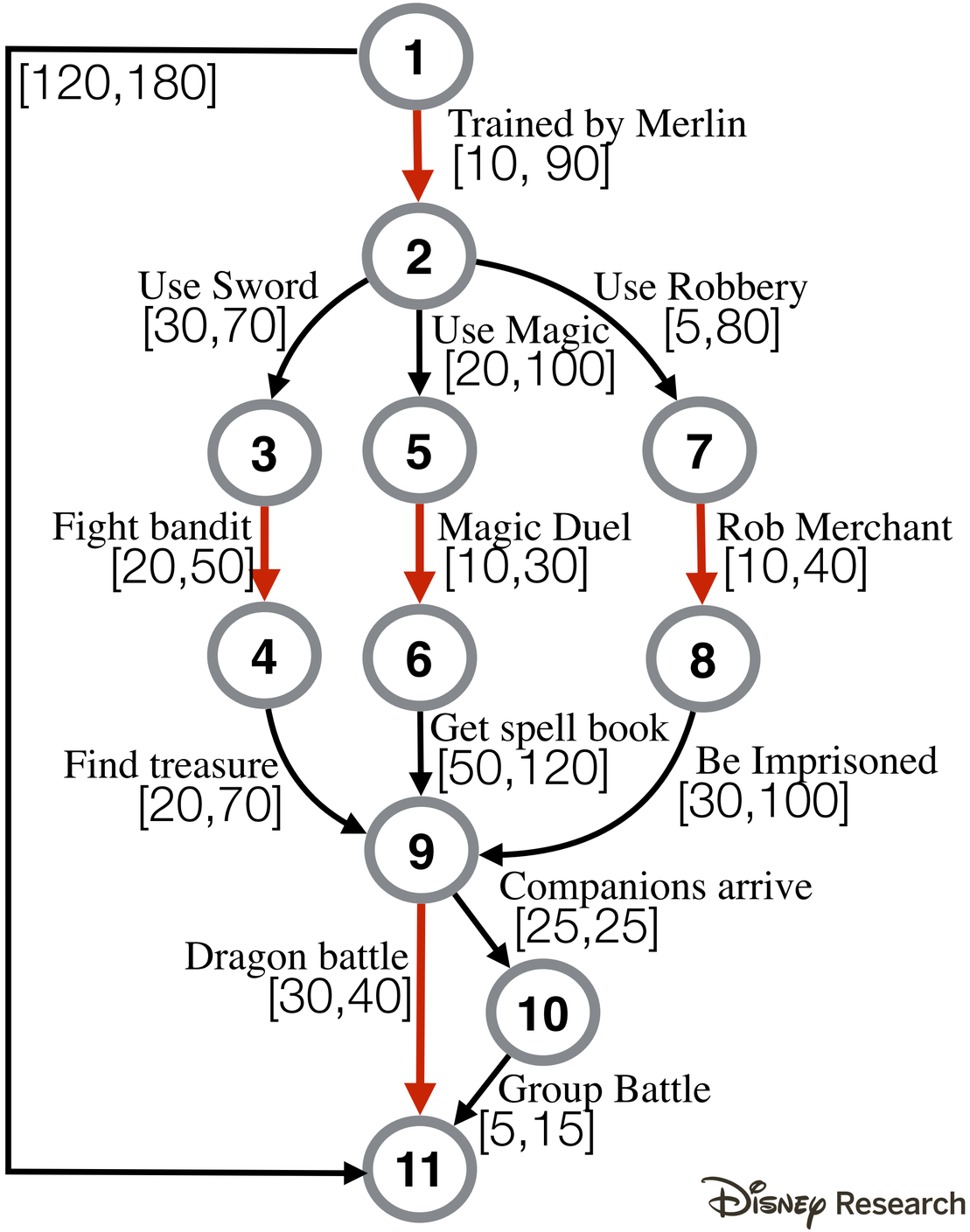
Challenges with Live Interactive Narratives

- High cost for authoring and reauthoring
- Time taken to complete events and interactions is inconsistent
- Authoring for consistent story beats or dramatic tension
- Mitigation of real world operating costs

People don’t understand time. People assume that time is a strict progression of cause to effect, but actually from a non-linear, non-subjective viewpoint, it's more like a big ball of wibbly-wobbly, timey-wimey stuff.
— Doctor Who (Series 3, Episode 10 - Blink)

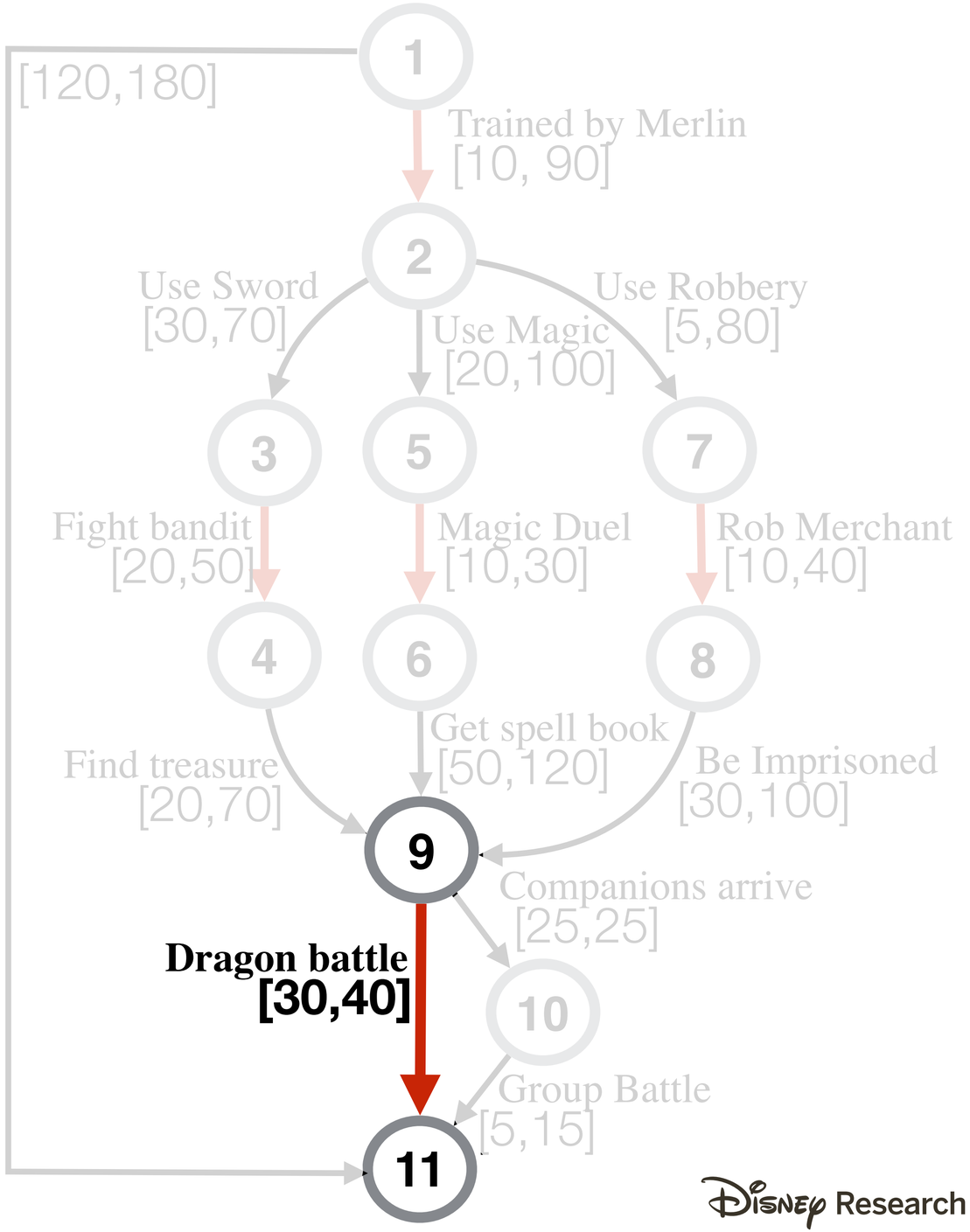
Temporal Challenges with Narratives

- Dependency graph with temporal durations of events.



Temporal Challenges with Narratives

- Dependency graph with temporal durations of events.
- Contingent (or Uncontrollable) events



Temporal Challenges with Narratives

- Dependency graph with temporal durations of events.
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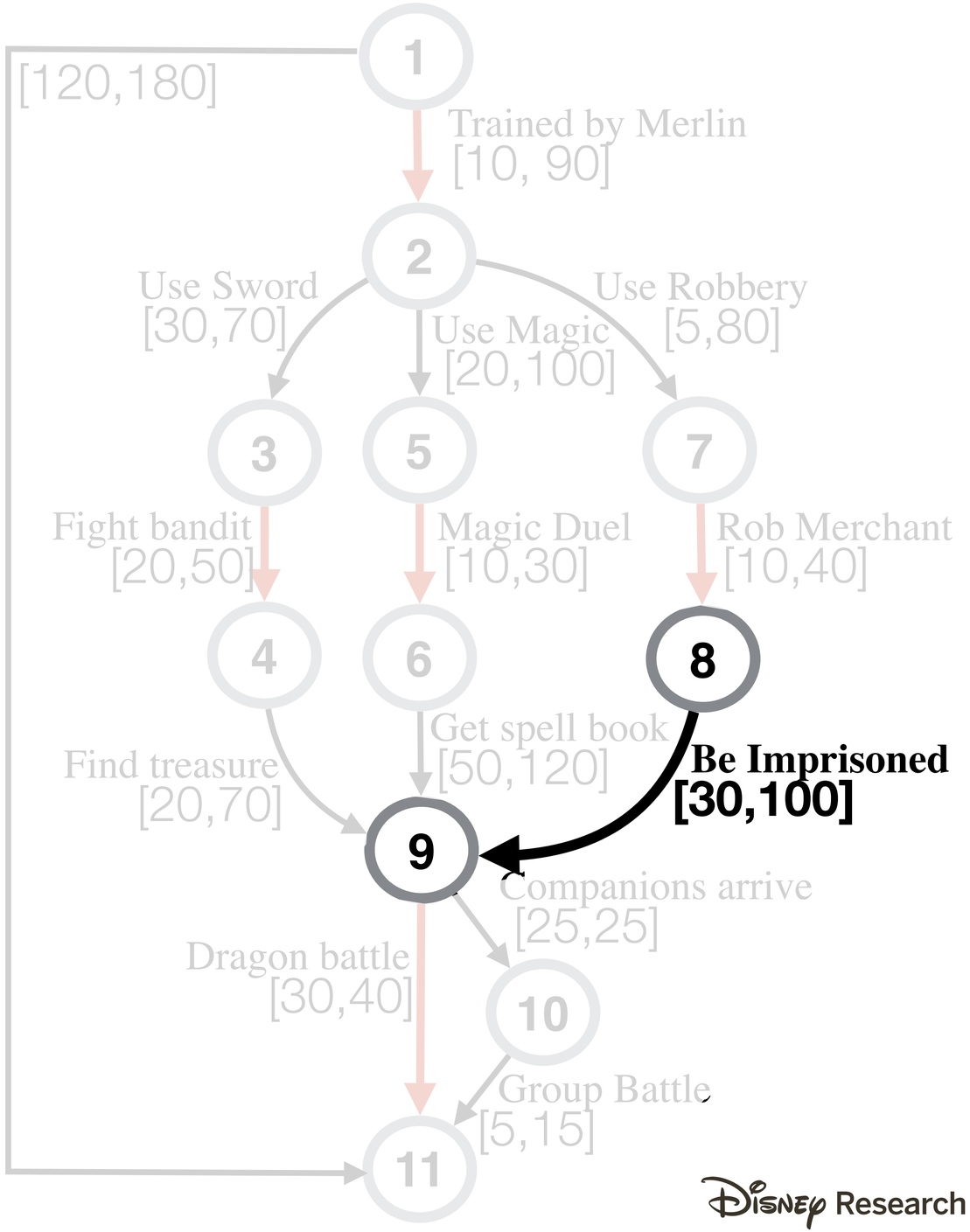
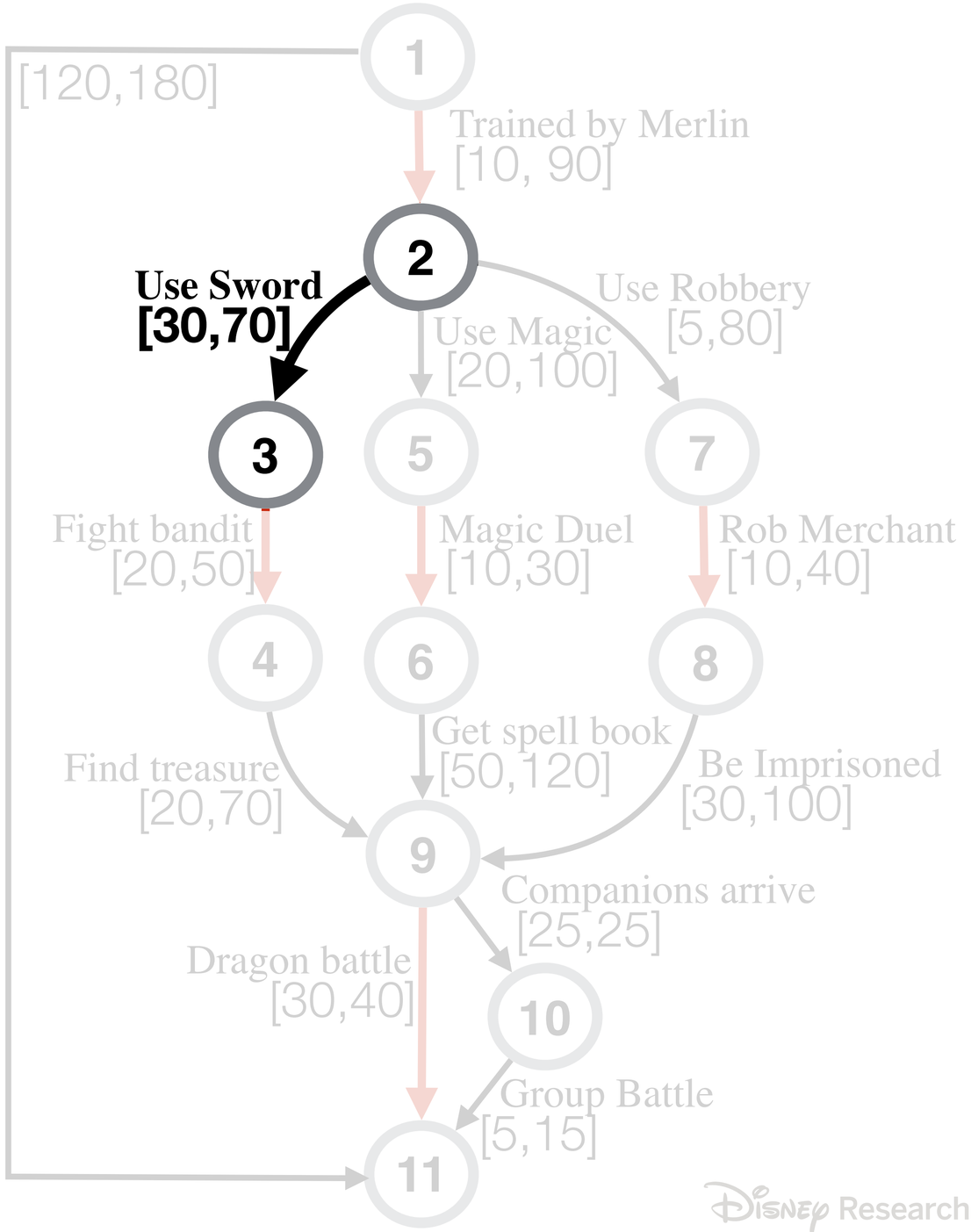
- Requirement (or Controllable) events



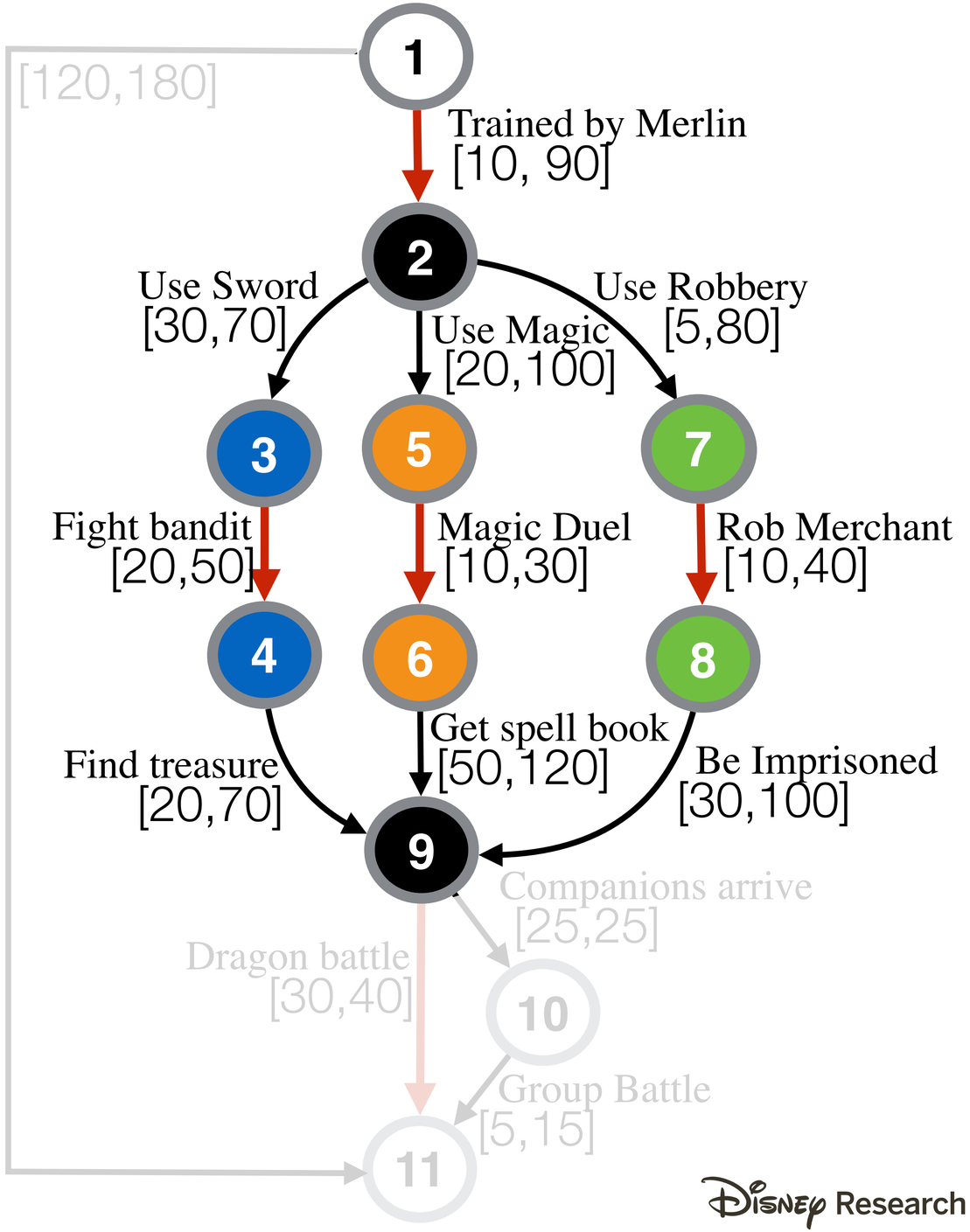
Temporal Challenges with Narratives

- Dependency graph with temporal durations of events.
- Contingent (or Uncontrollable) events
- Requirement (or Controllable) events
- Resource availability
  - Original available
  - Produced during an event
  - Consumed during an event



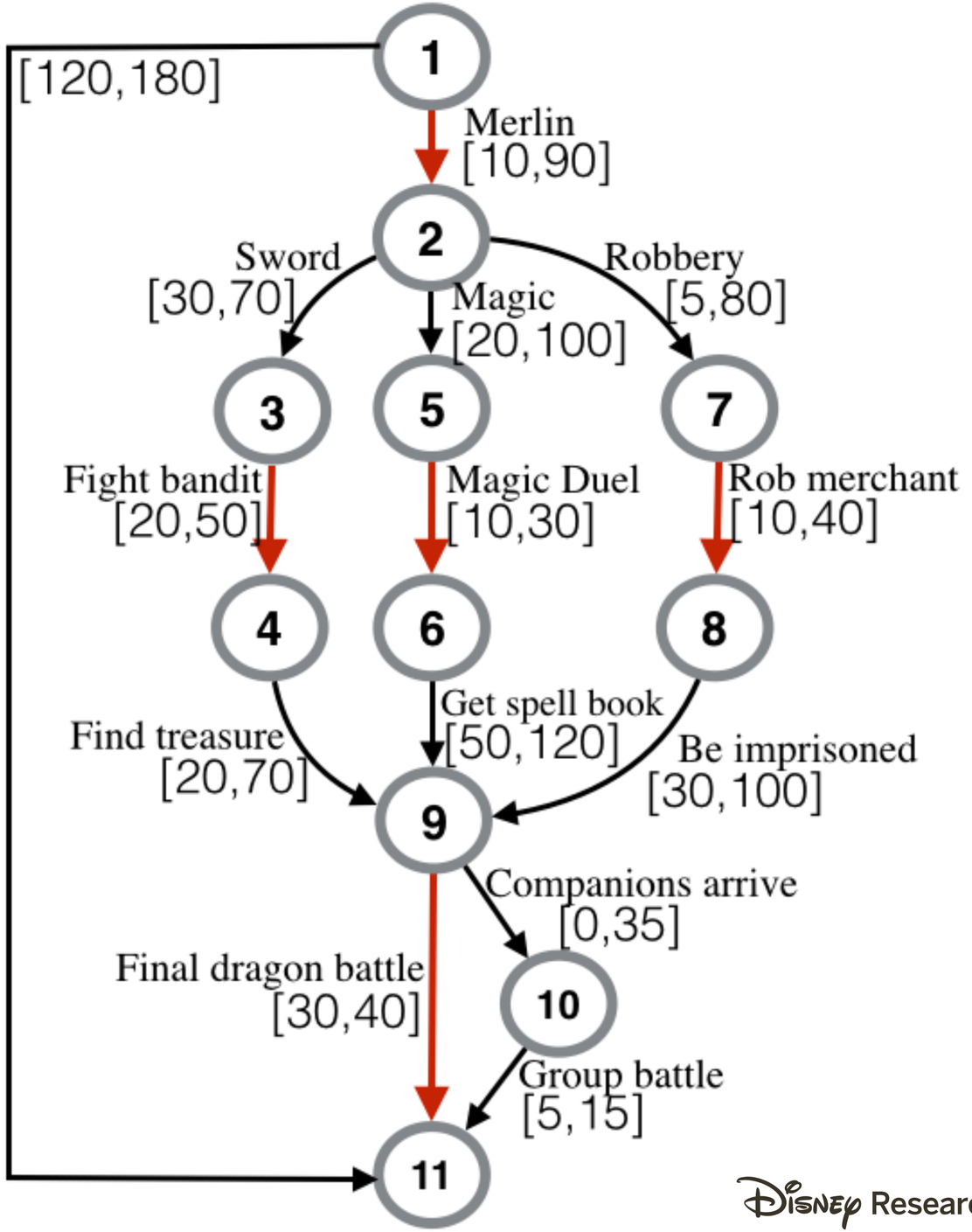
Temporal Challenges with Narratives

- Dependency graph with temporal durations of events.
- Contingent (or Uncontrollable) events
- Requirement (or Controllable) events
- Resource (original, produced, consumed)
- Plot choices!



Problem Statement

- **Given:**
  - Uncontrollable durations
  - Constraints on controllable durations
  - Constraints on resources
  - Plot choices
- **No peeking into the future**
- **Change the duration**
  - Controllable time points
  - Any uncontrollable observed duration



Live Interactive Narratives Scheduling Problem (LINSP)

Live Interactive Narrative Scheduling Problem (LINSP)

- Formulated as a mixed integer linear programming constraint satisfaction problem
- A LINSP problem is defined as a tuple

$$\langle V, E_{req}, E_{ctg}, U, L, A, b, R, M \rangle$$

Temporal / Narrative Bounds

Resource Constraints

Mutually Exclusive Constraints

Temporal Constraints

Shortest Path Constraints

$$l_{AC} \leq u_{AB} + l_{BC} \leq u_{AC}$$
$$l_{AC} \leq l_{AB} + u_{BC} \leq u_{AC}$$
$$u_{AC} \leq u_{AB} + u_{BC}$$
$$l_{AB} + l_{BC} \leq l_{AC}$$

Precede Constraints

$$u_{AB} \leq l_{AC} - l_{BC}$$
$$l_{AB} \geq u_{AC} - u_{BC}$$

Unordered Constraints

$$(l_{BC} < 0) \vee \begin{pmatrix} u_{AB} \leq l_{AC} - l_{BC} \\ l_{AB} \geq u_{AC} - u_{BC} \end{pmatrix}$$

Wait Constraints for this triangle

$$w_{ABC} \geq u_{AC} - u_{BC}$$

Wait Constraints for overall story

$$l_{AB} \geq min(l_{AX}, w_{ABX})$$
$$w_{ADX} \geq w_{ABX} - l_{DB}$$
$$(w_{ABX} < 0) \vee (w_{ADX} \geq w_{ABX} - l_{DB})$$

Sequencing for resources used

$$l_{S_i S_j} \geq u_{S_i E_i} - M * (1 - x_{i,j}), \qquad i < j$$
$$x_{i,j} + x_{j,i} \leq 1, \qquad \forall (i,j) \in \{0, \ldots, n+1\}^2$$
$$x_{i,k} \geq x_{i,j} + x_{j,k} - 1, \ \forall (i,j,k) \in \{0, \ldots, n+1\}^3$$

Live Interactive Narrative Temporal Constraints

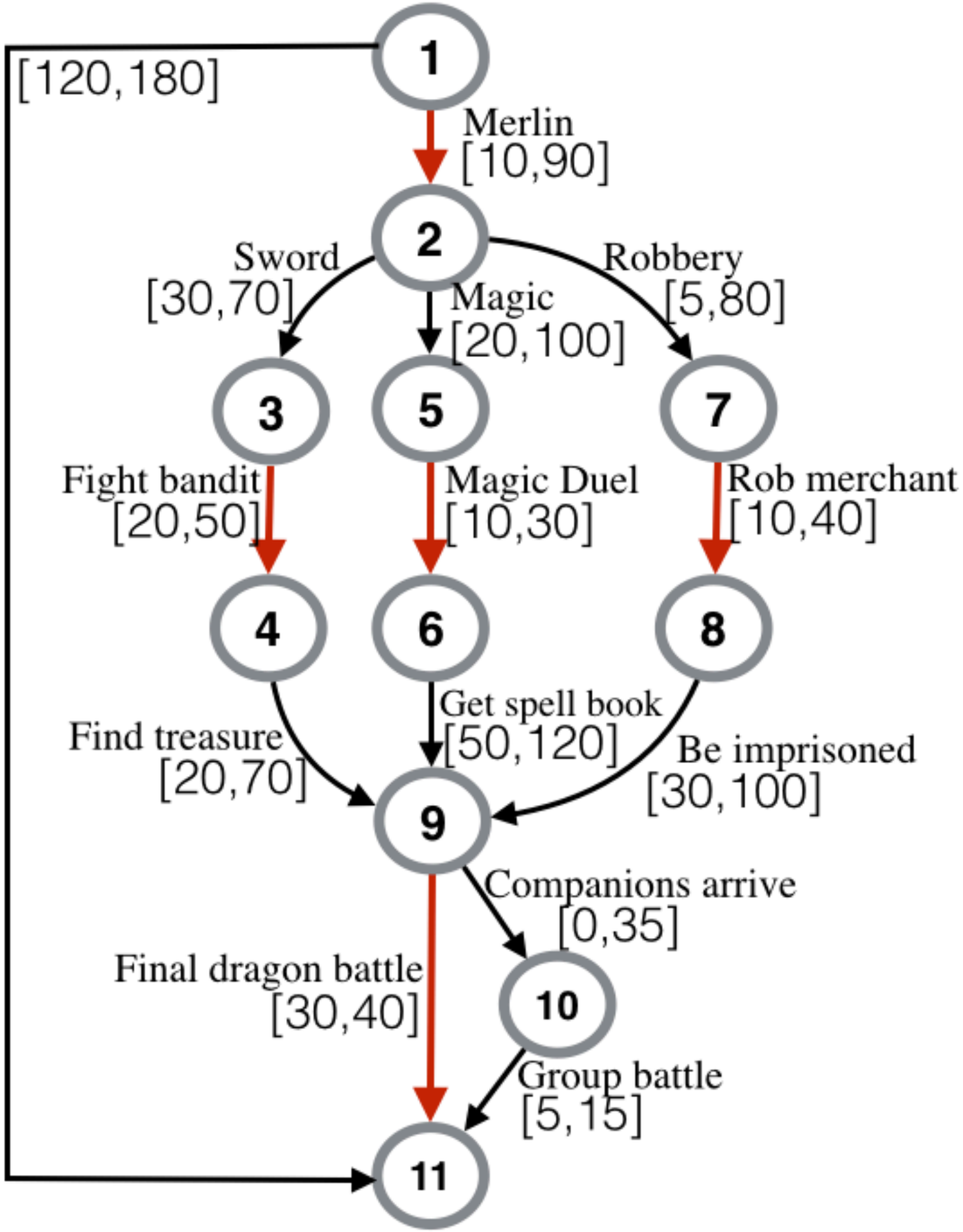
Prior Work

- **Shortest Path Constraints**
- **Follow Constraints**
  If activity A follows B
- **Precede Constraints**
  If activity A occurs before or at the same time as B
- **Unordered Constraints**
  If activity A and B are scheduled independently
- **Wait Constraints**
  Activity B must wait for either
  1) a minimum time, or 2) till after a specific event A is over

Our Contribution

- **Plot Choice Constraints**
  Accounts for interactive narrative choices that may be mutually exclusive to each other
- **Resource Flow Constraints**
  Accounts for available resources flowing in a narrative
- **Resource Consumption Constraints**
  Accounts for activities that consume resources
- **Resource Production Constraints**
  Accounts for activities that can produce or consume resources

The Great Dragon Adventure



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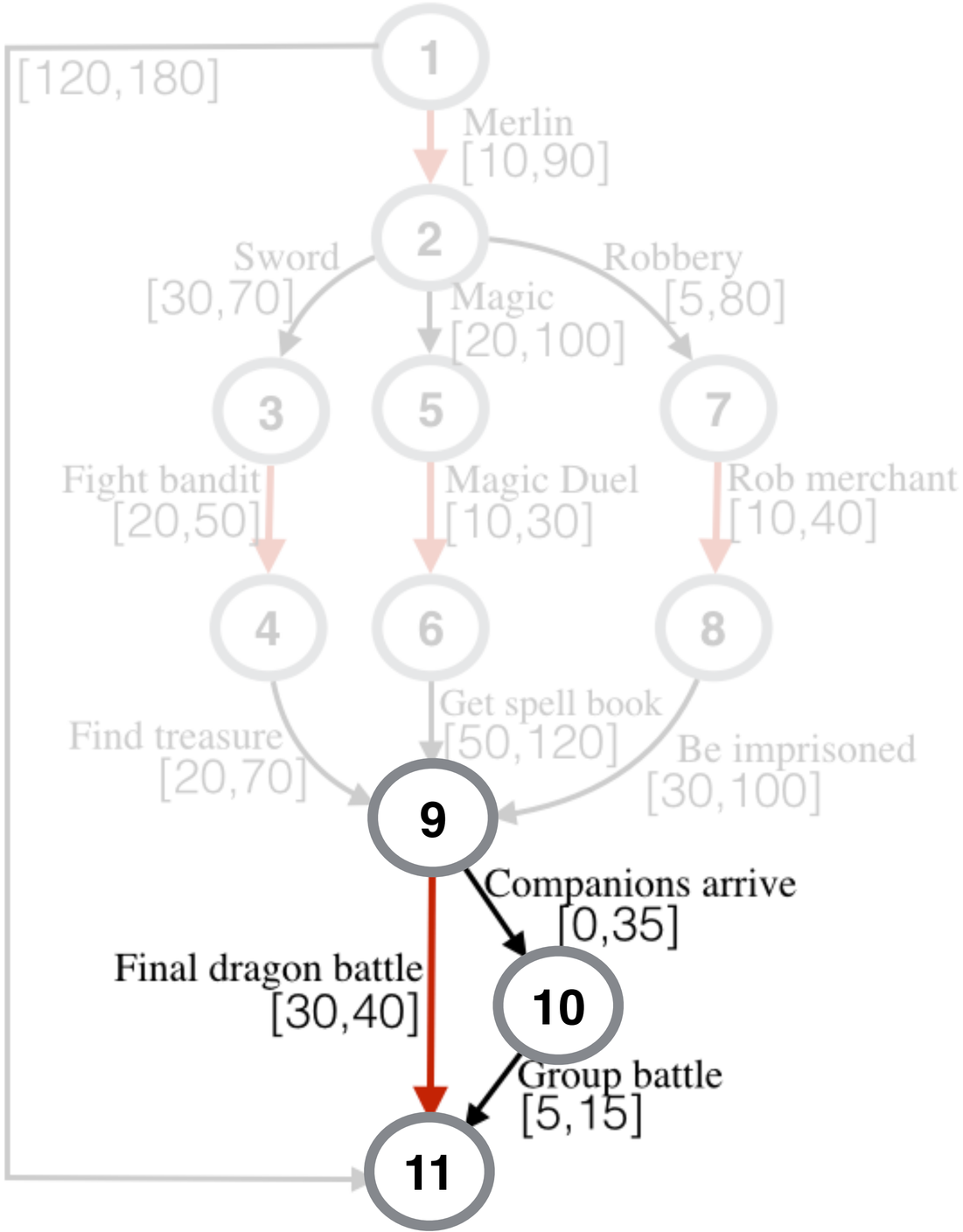
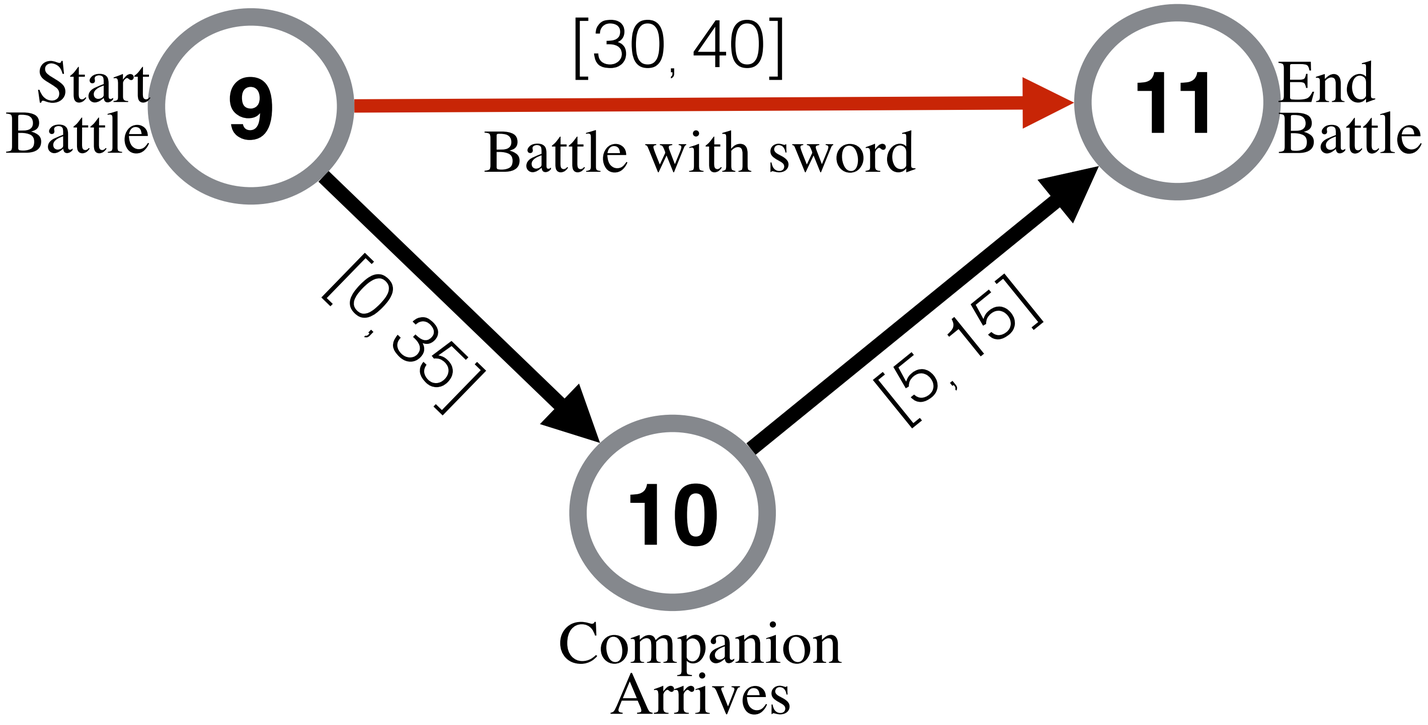
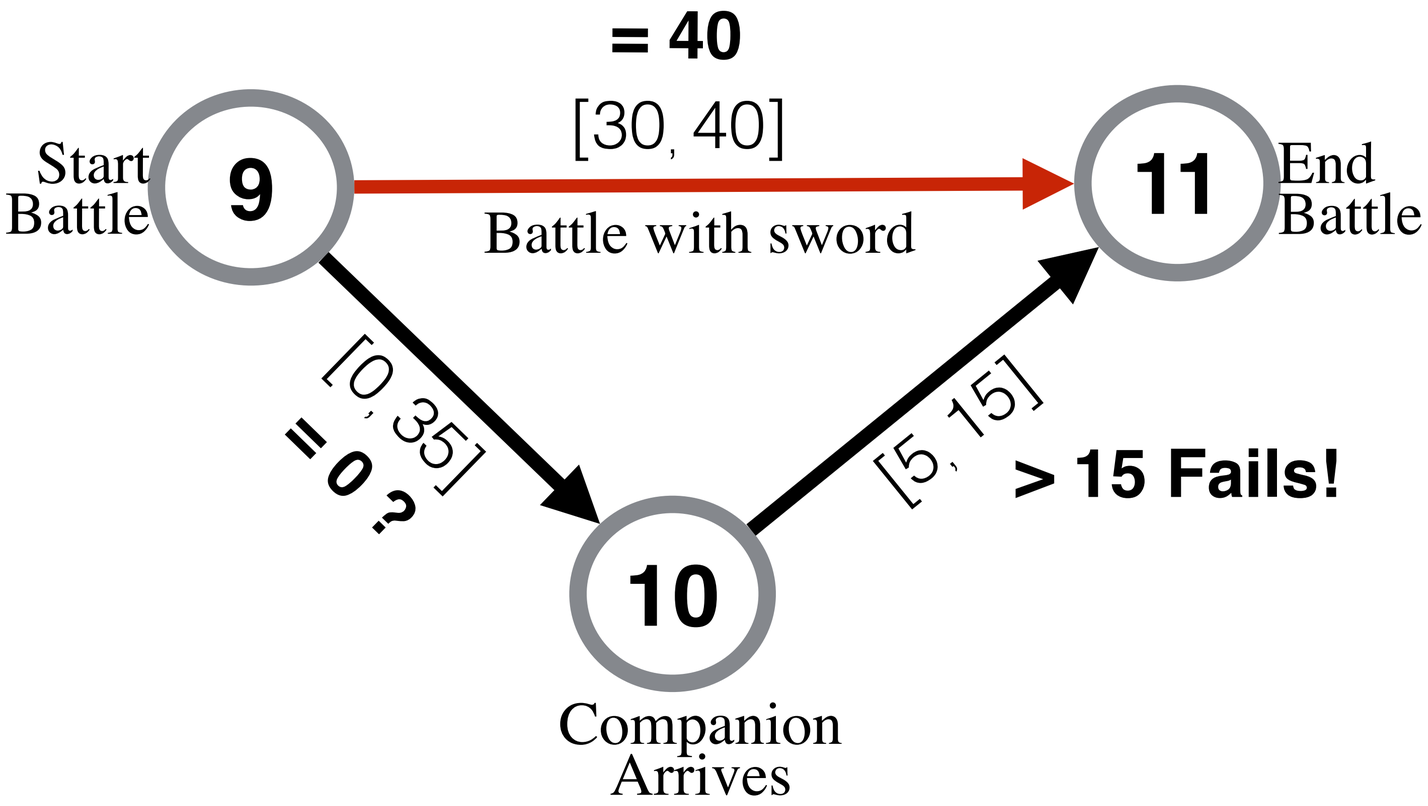




Requirement (controllable)

Contingent (uncontrollable)



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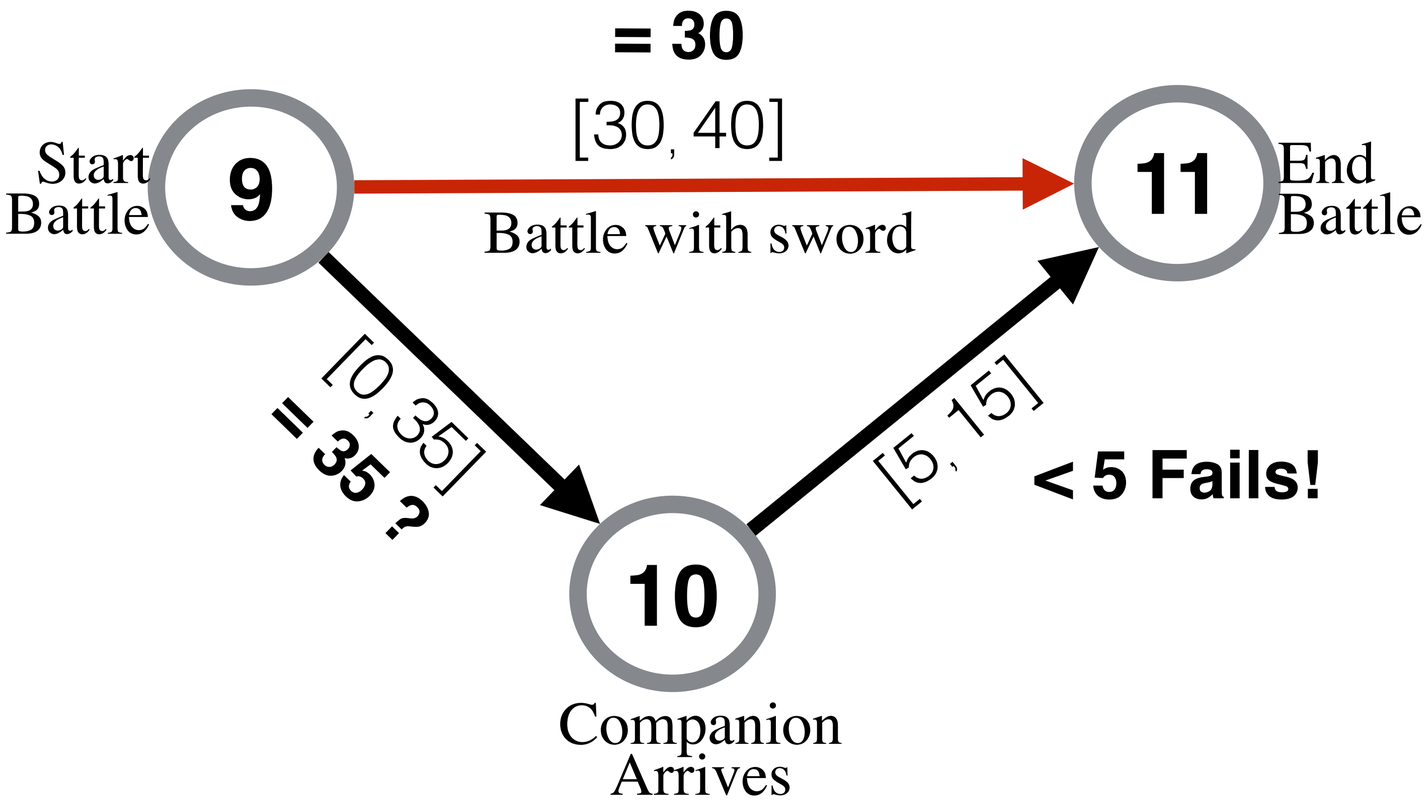

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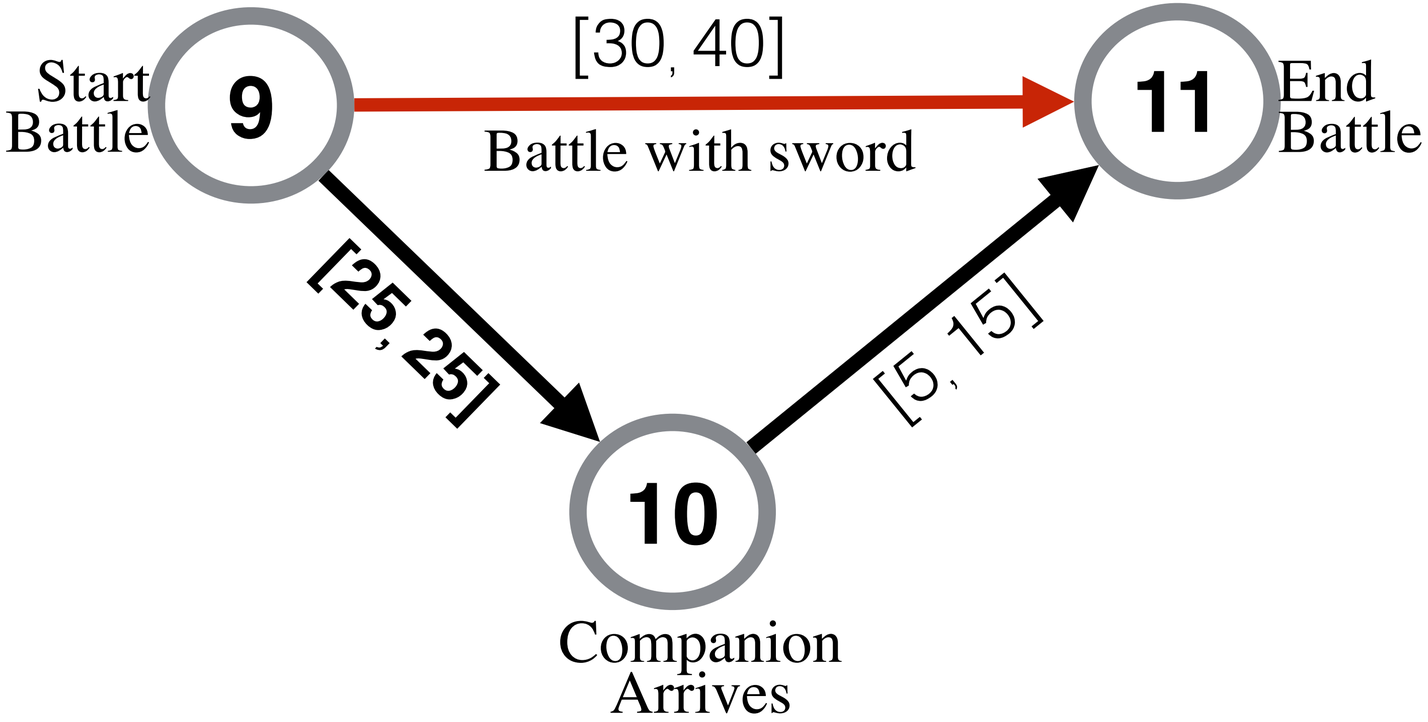
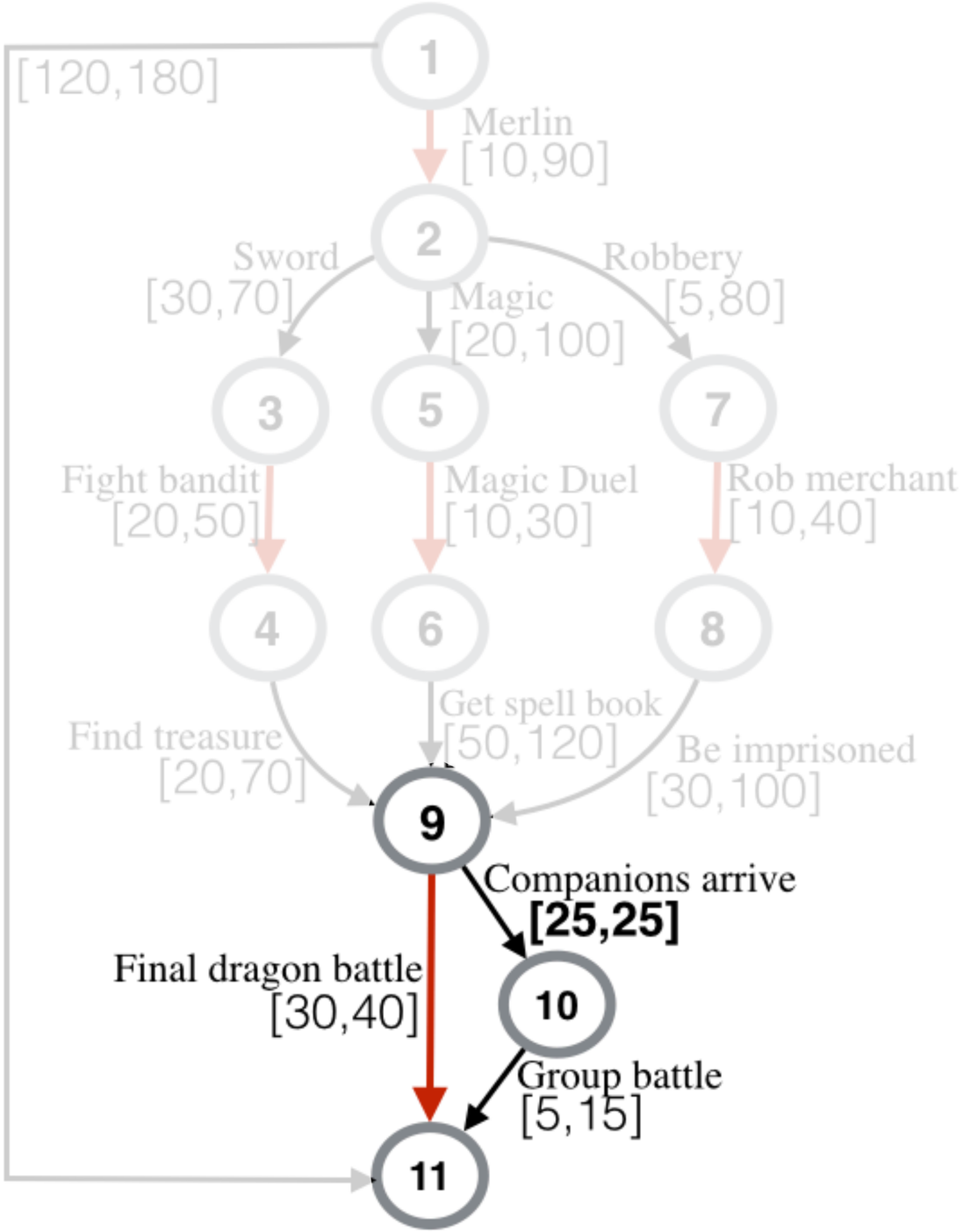


Dynamically Controllable!

Requirement (controllable)

Contingent (uncontrollable)

Simple Temporal Problem with Uncertainty



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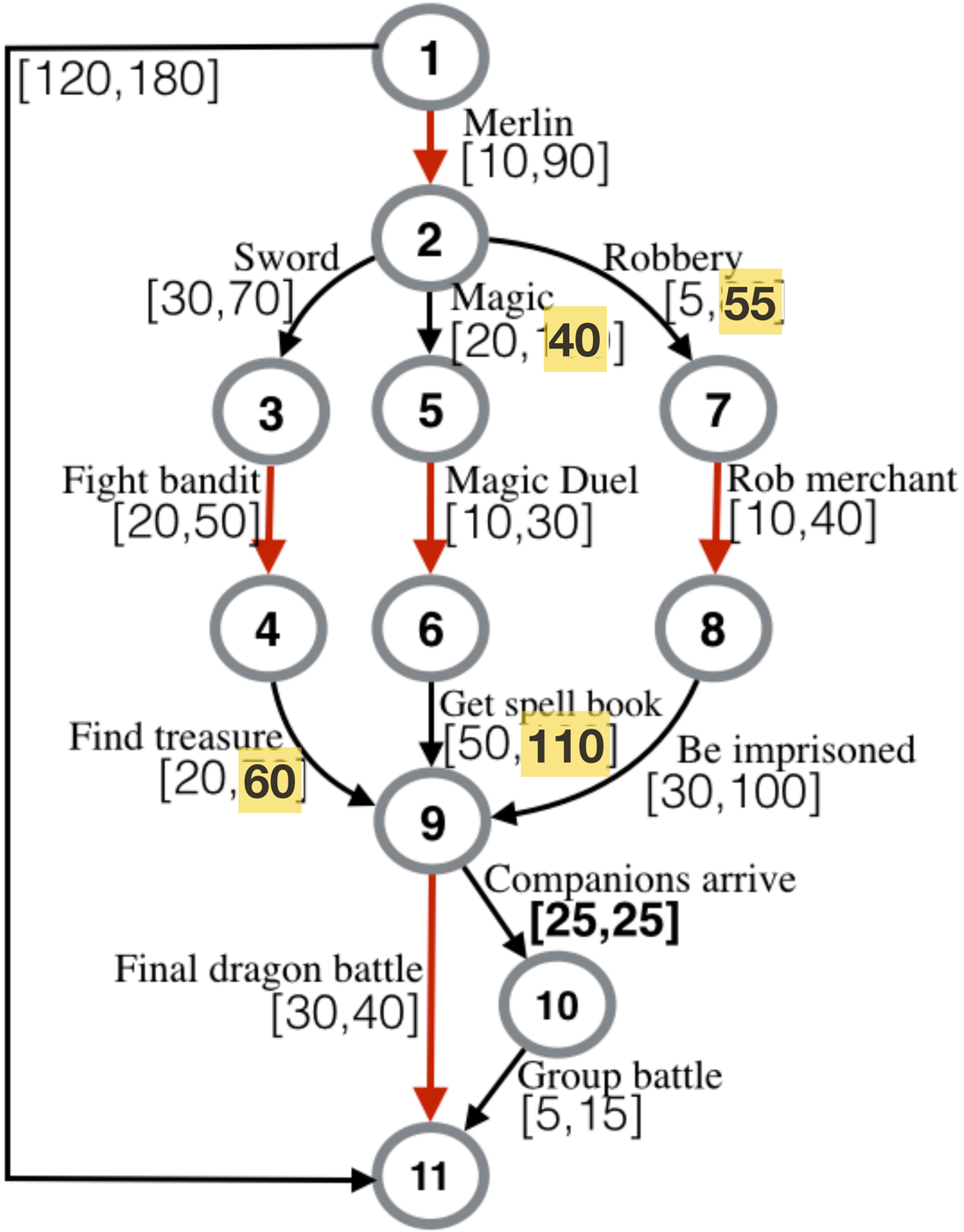
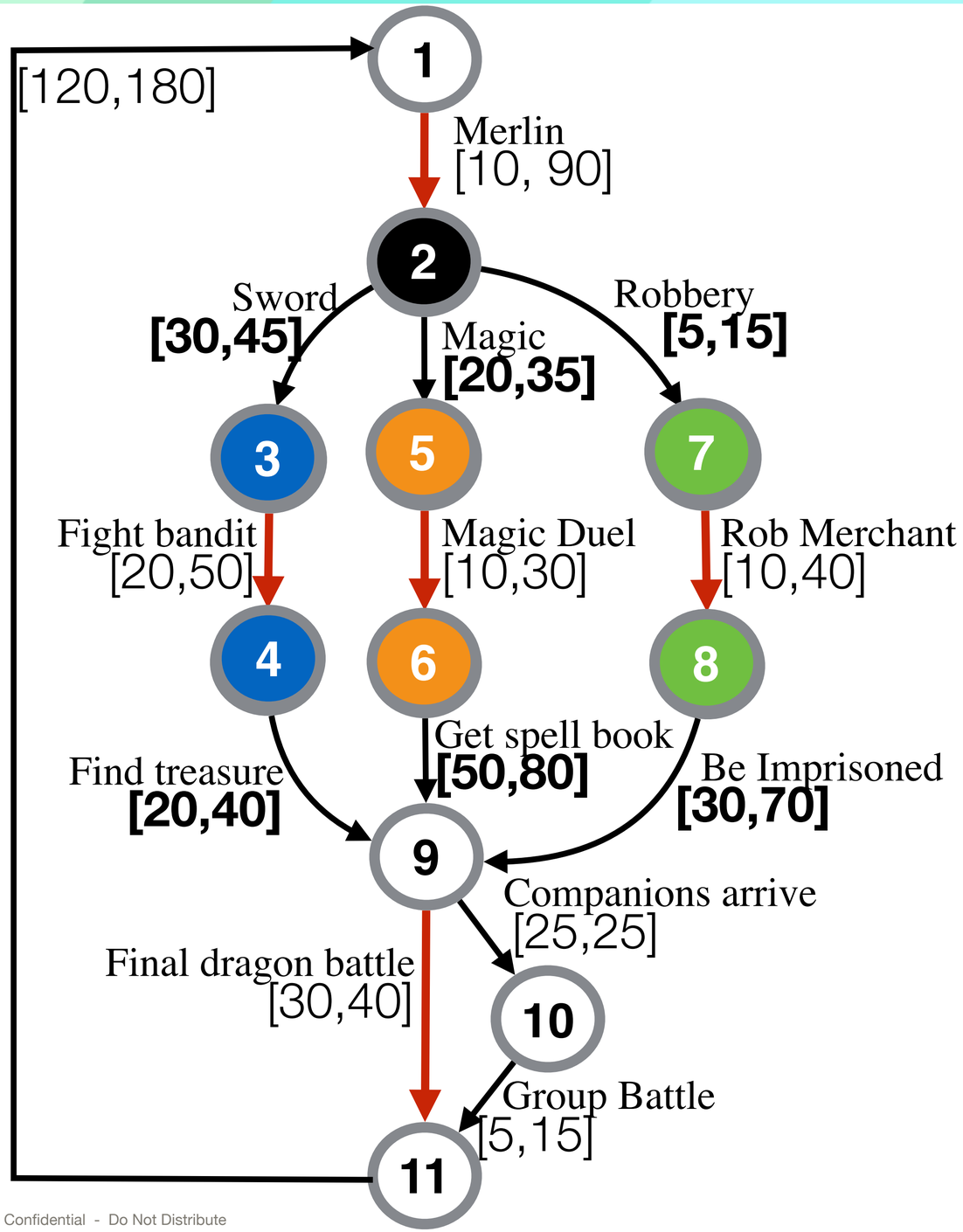
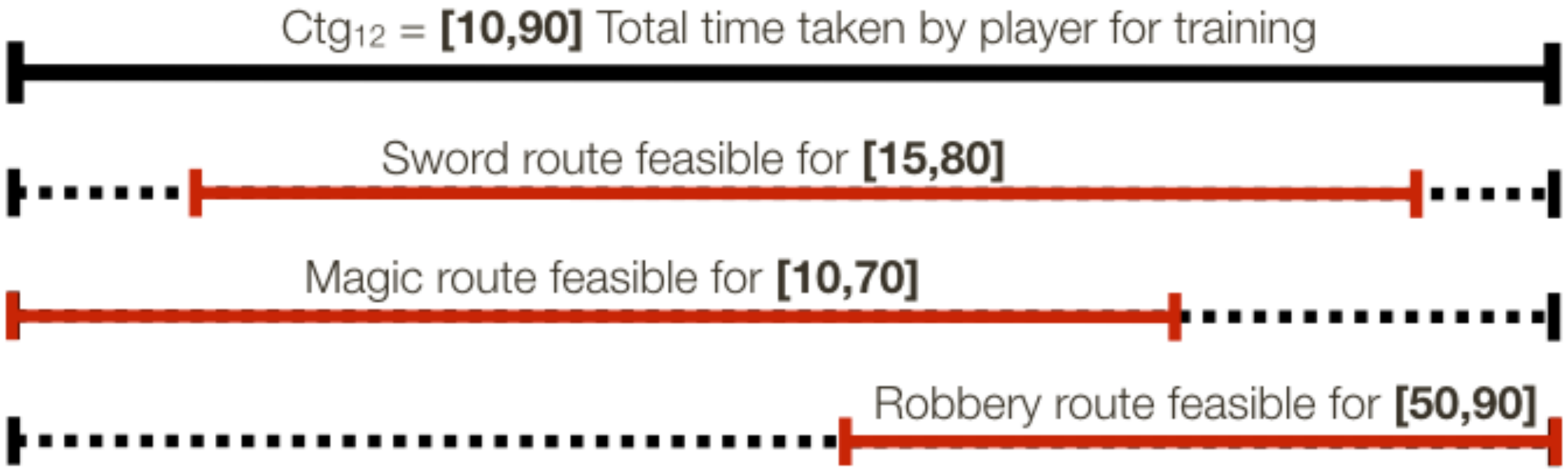


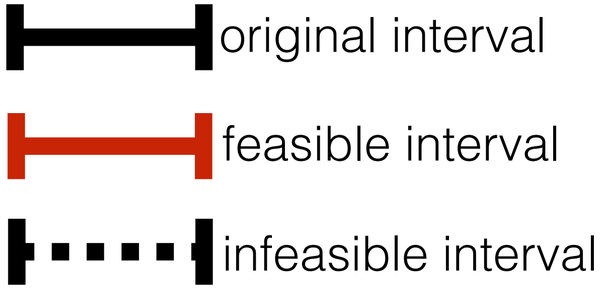




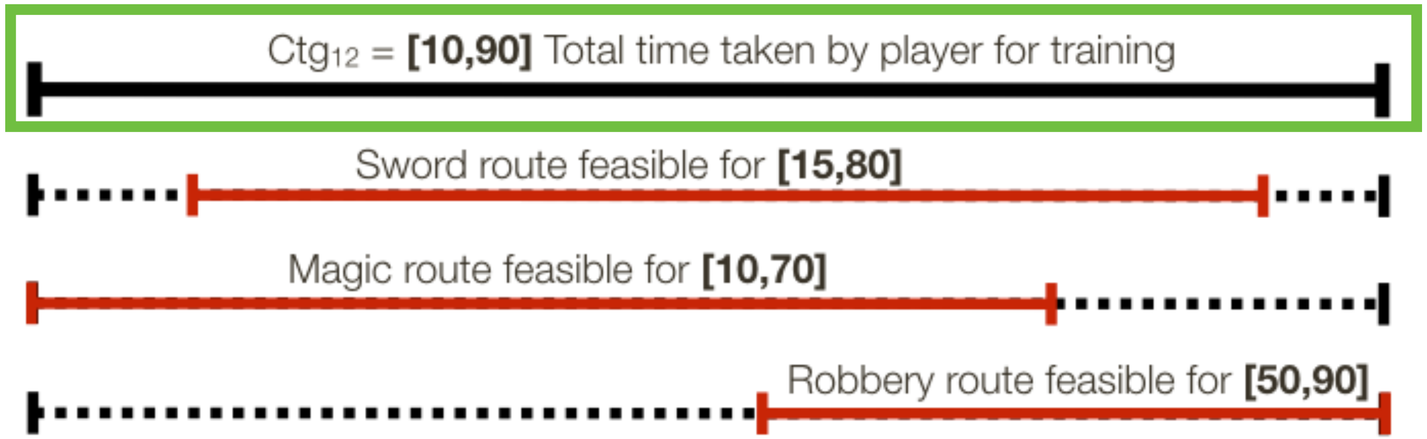
Entire Ctg [10,90] interval is covered!

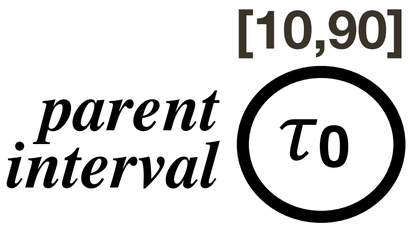
LIN Scheduler Plot Choices Constraint

We can allow individual plot choices and routes to not be feasible during a subset or interval of time of the original bound, as long as together they collectively cover the entire original interval.



Mutually Exclusive Plot Choices Constraints





- Every feasible plot choice interval is a node

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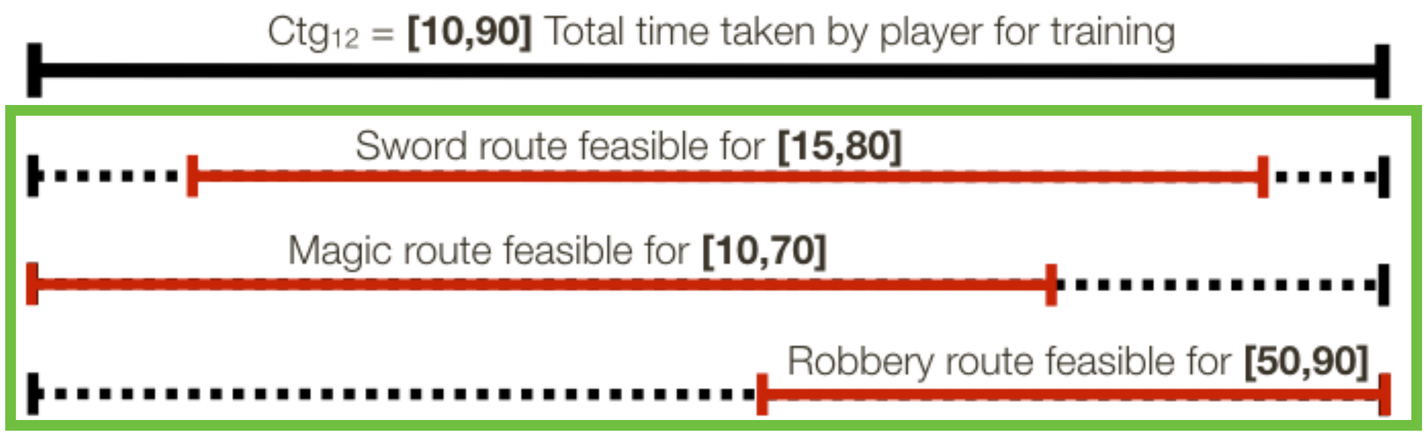

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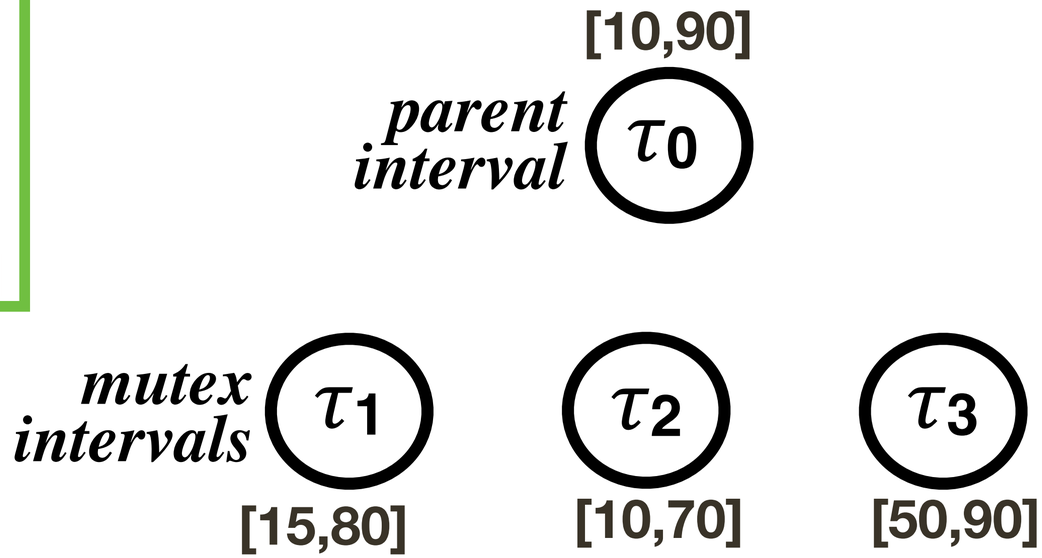

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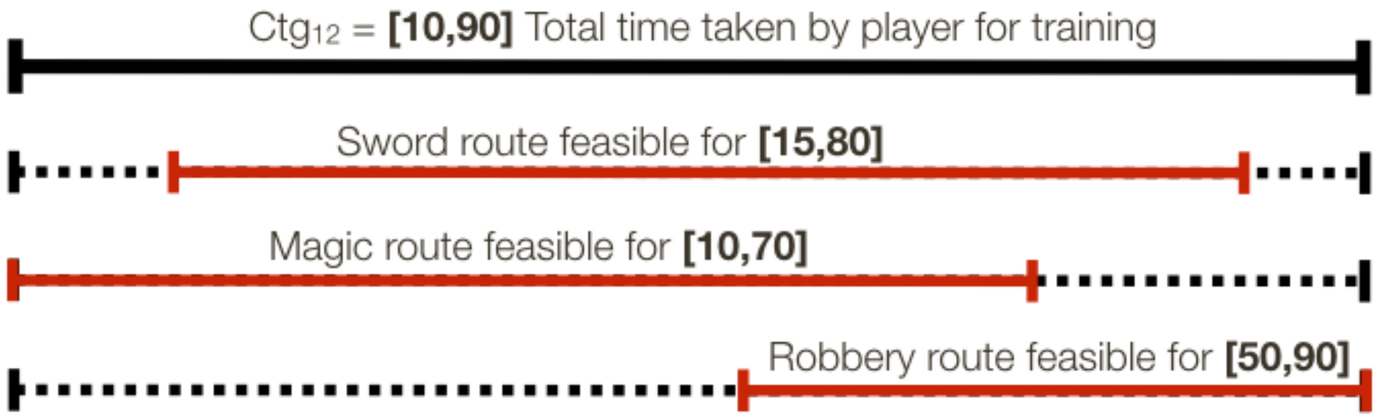

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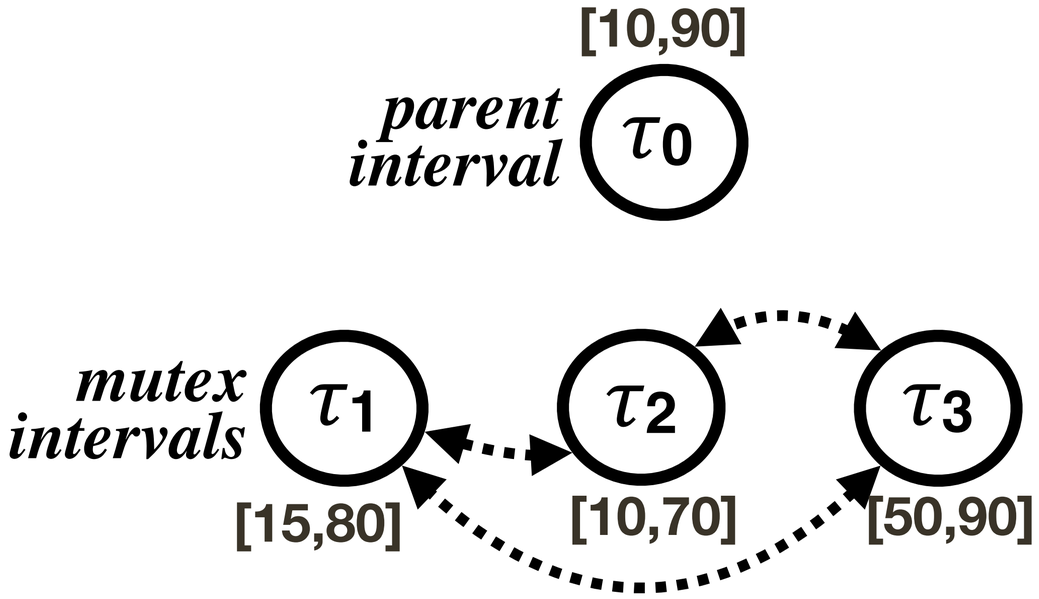
- Child Edge —> Overlap in temporal interval



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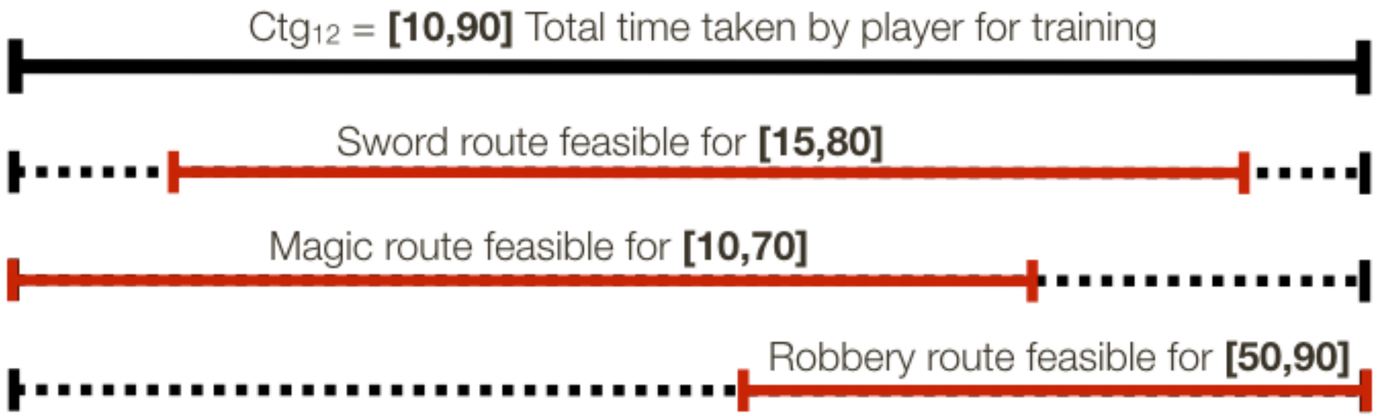
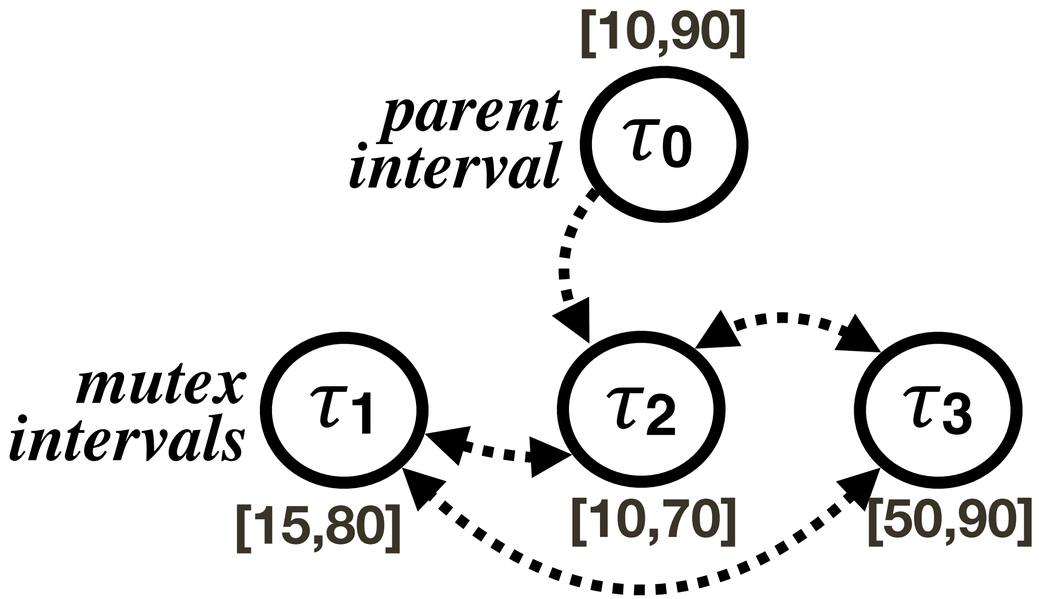


- Every feasible plot choice interval is a node
- Child Edge —> Overlap in temporal interval
- Parent Outward Edge —> Lower bound covered



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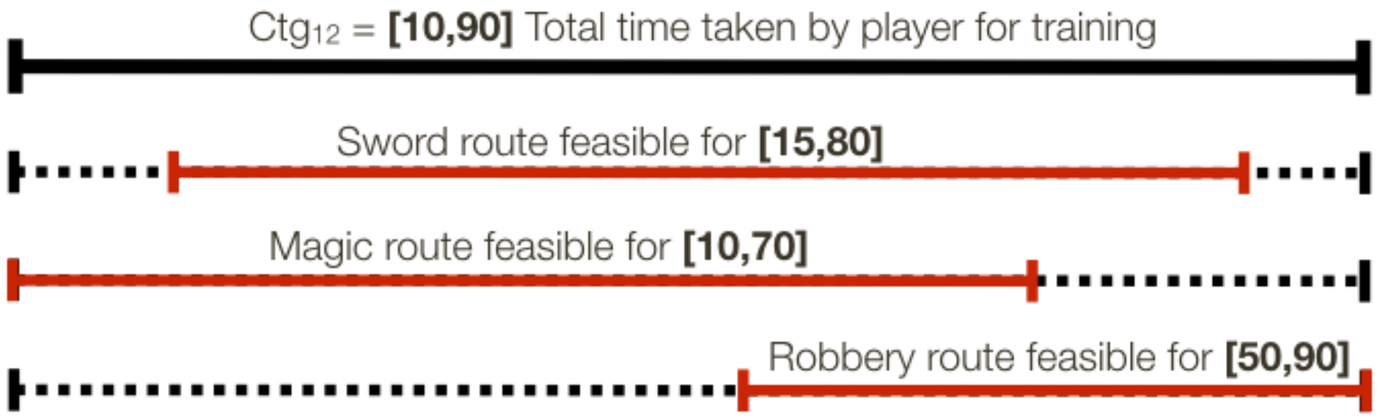

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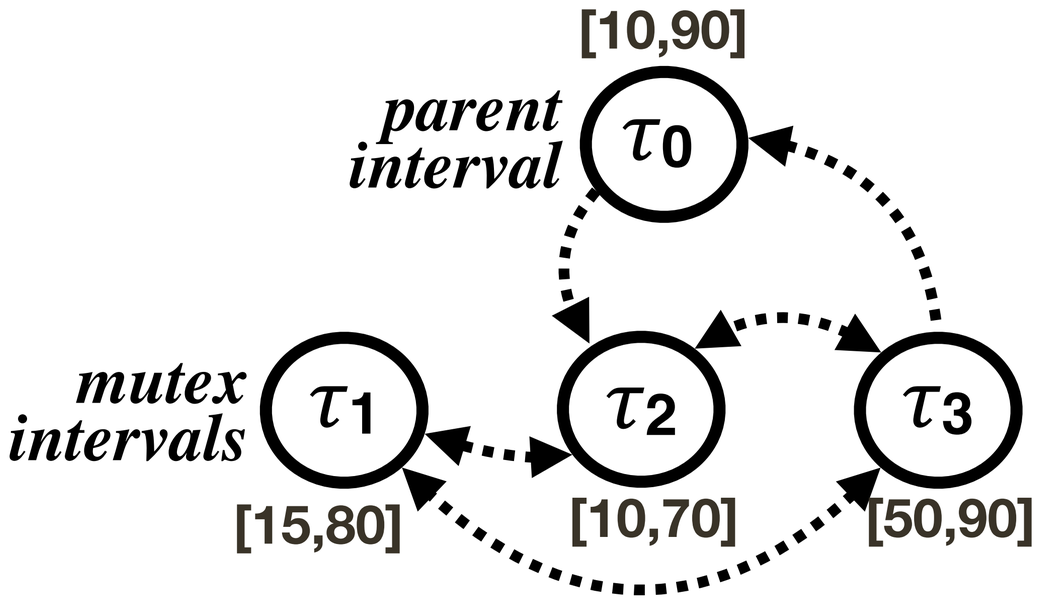

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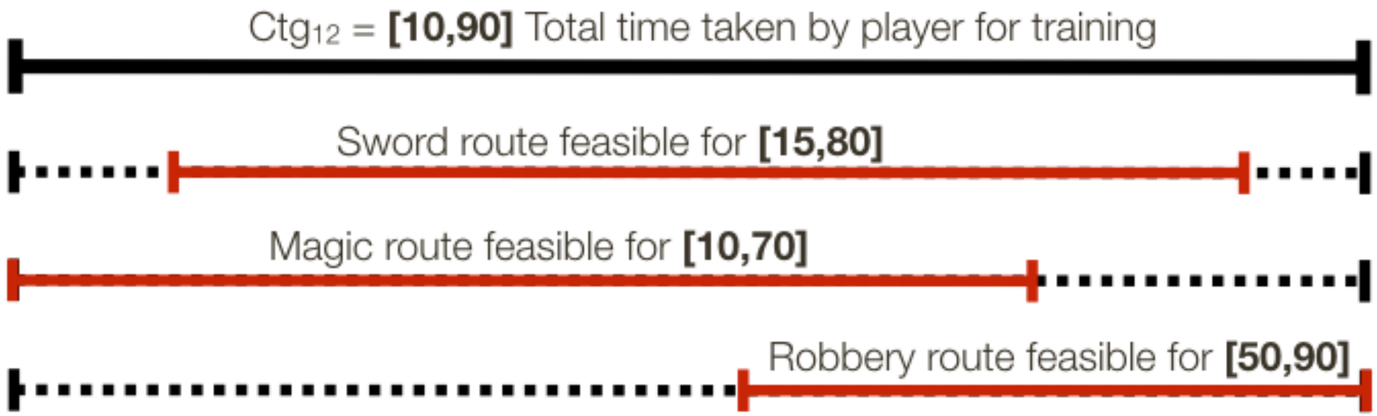

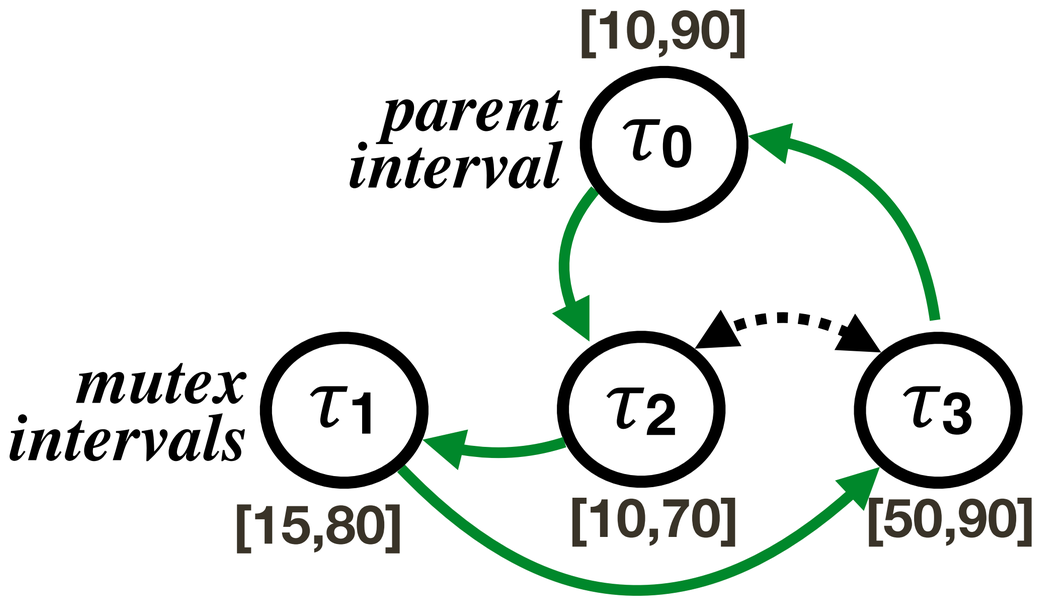

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- Cycle found must include parent and at least one mutex node

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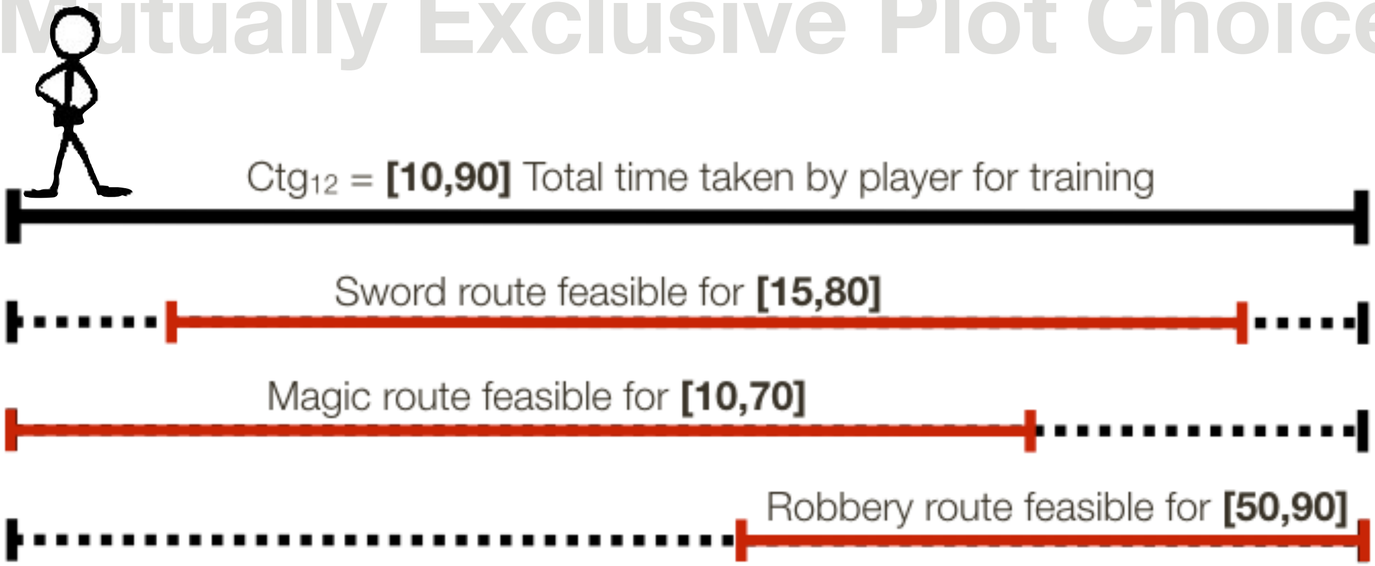

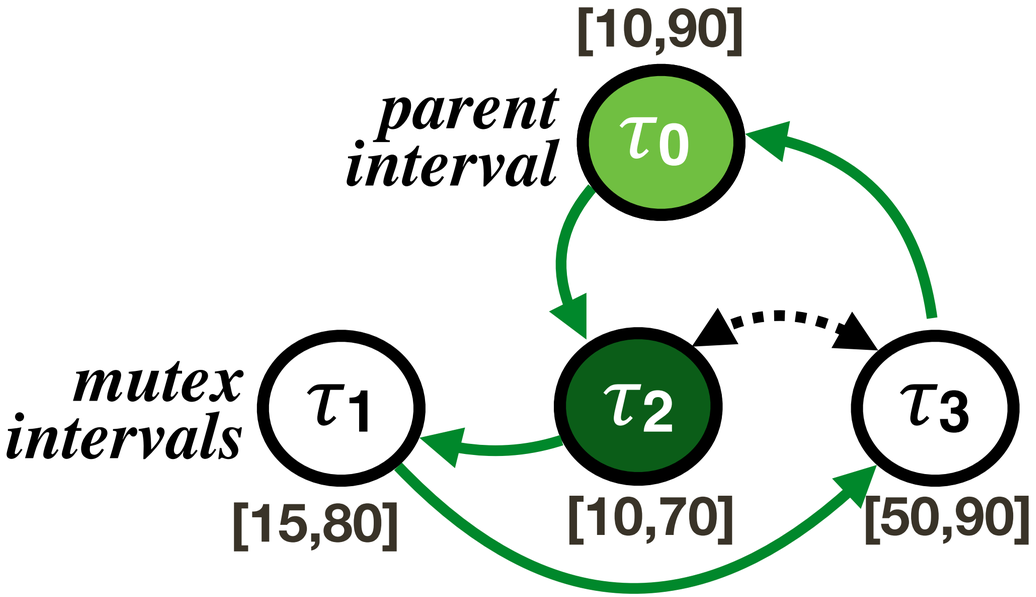

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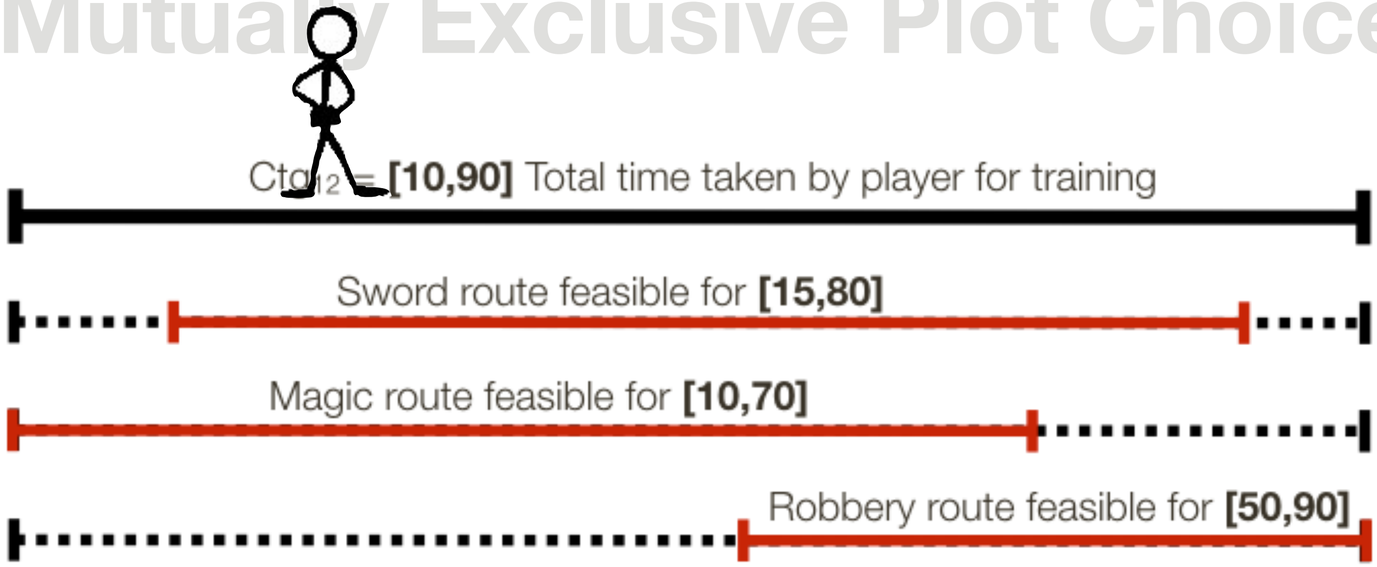

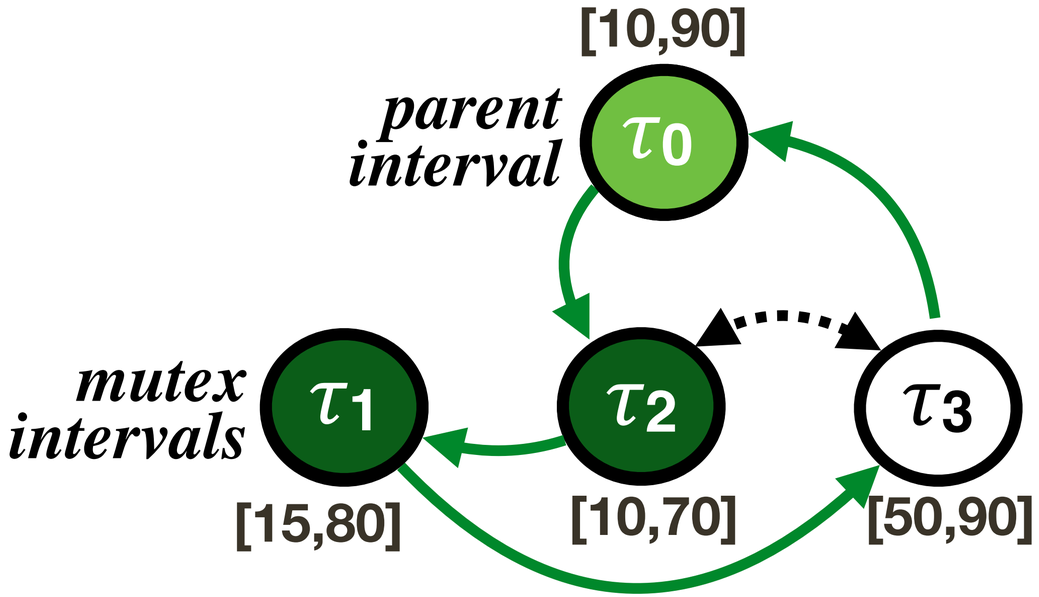

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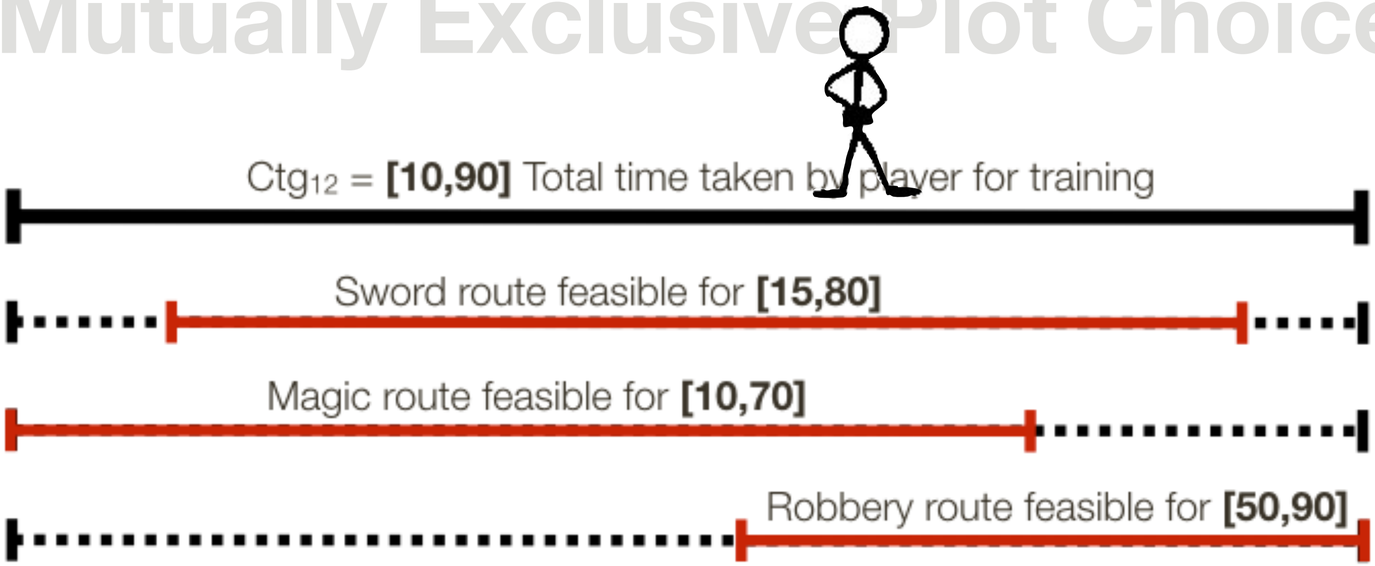

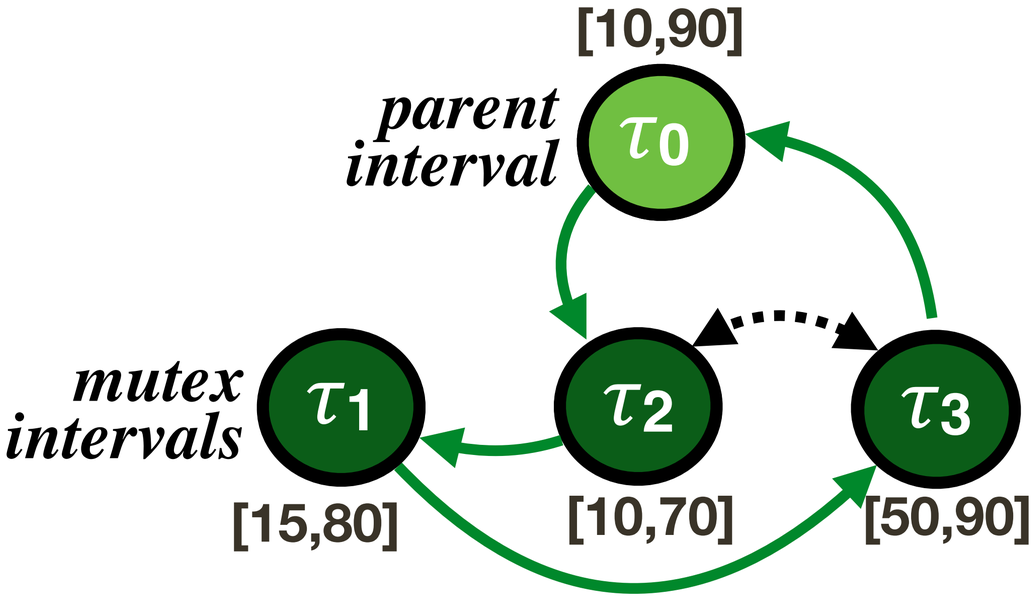

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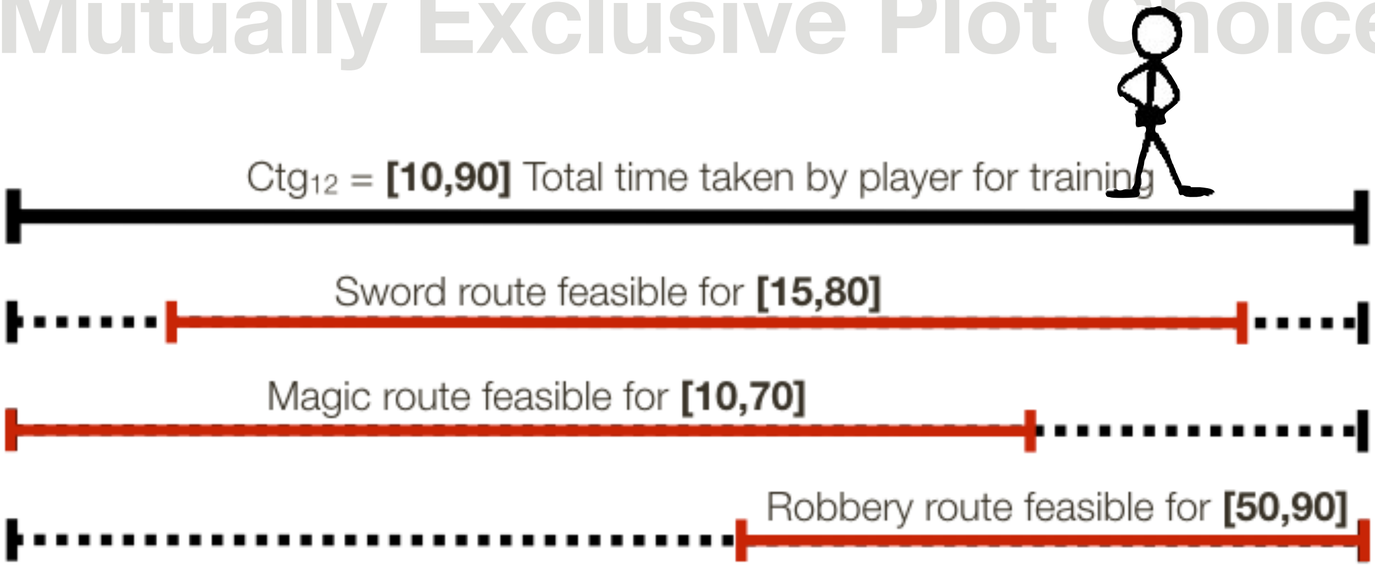

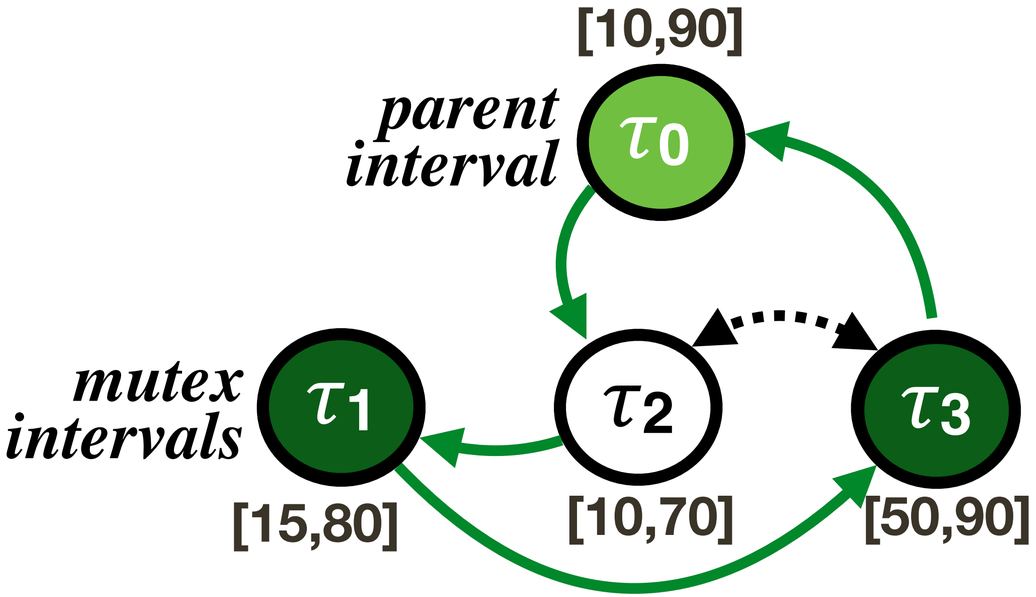

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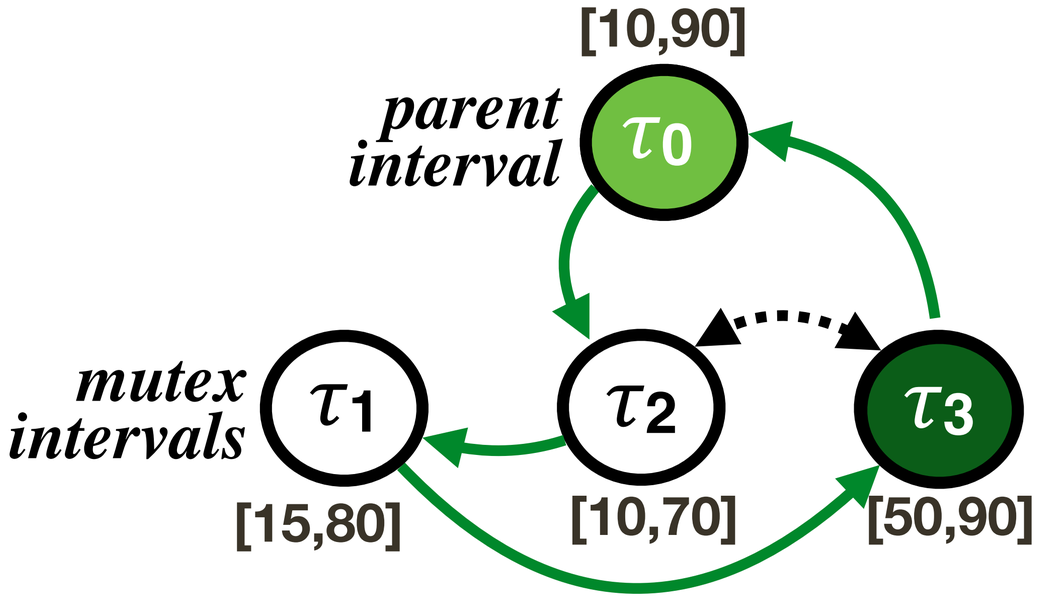

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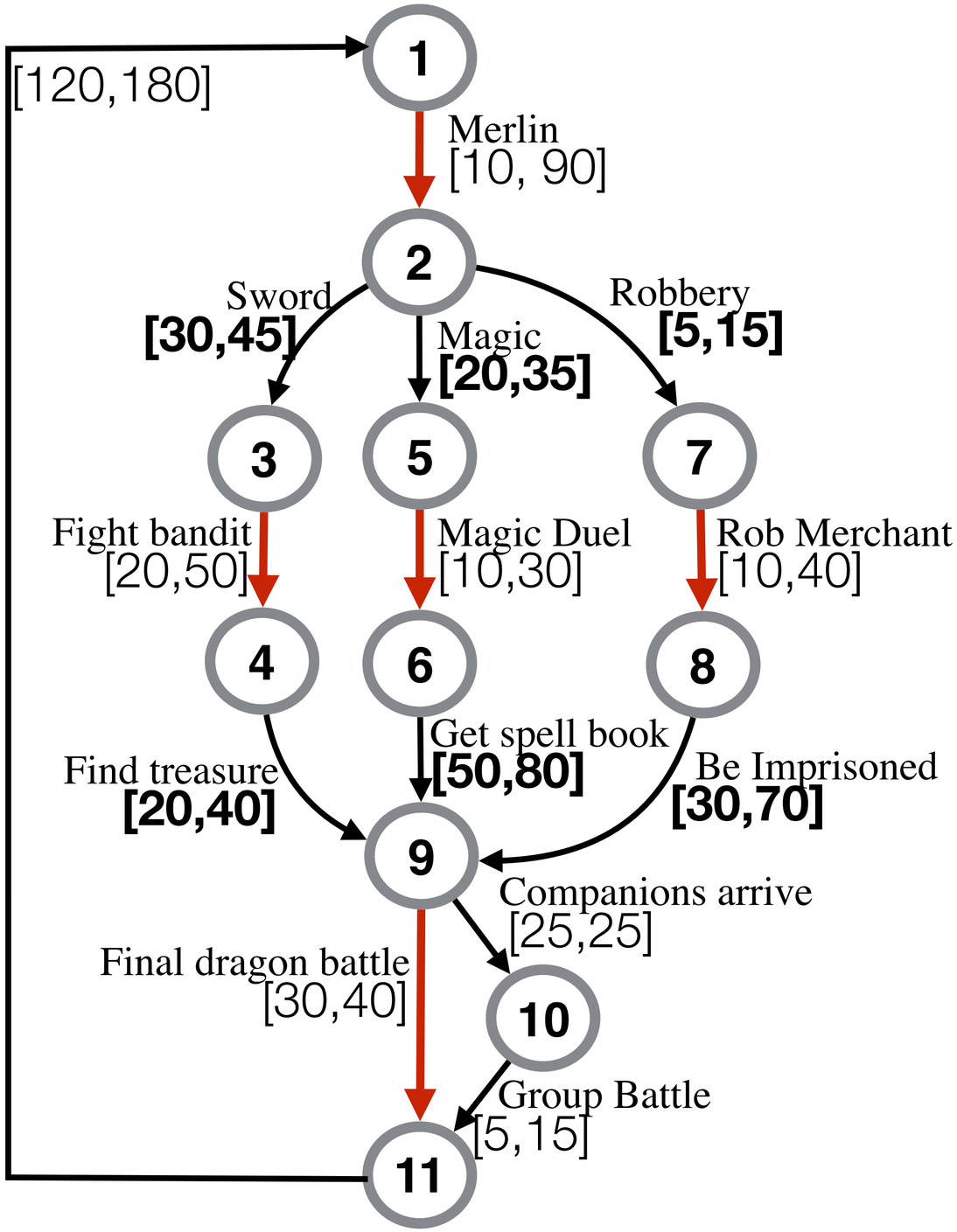
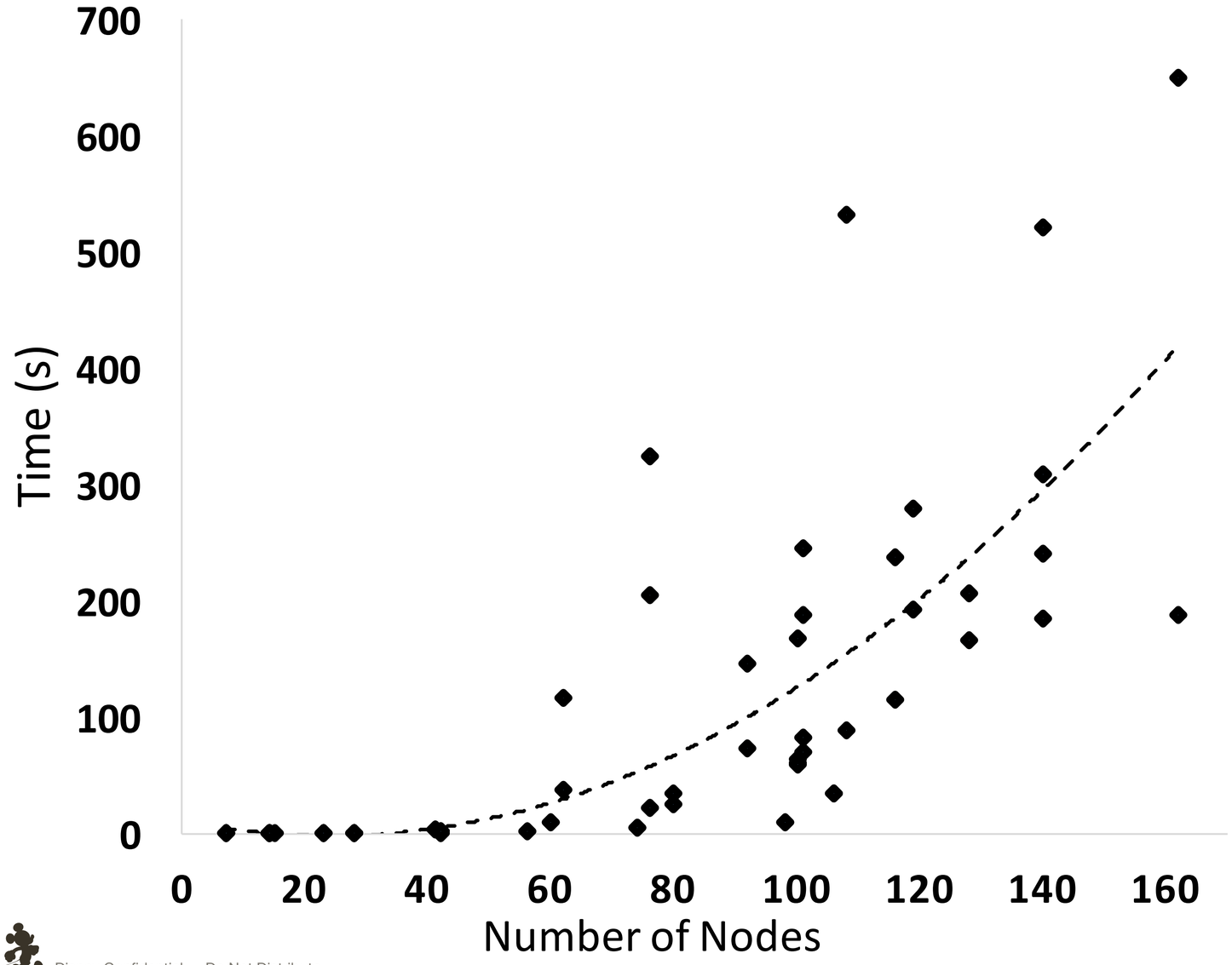


Evaluation

- NP hard!
- Lack of datasets
- Larger temporal durations imply the solution space explodes
- Dragon Adventure:
  - Number of linear programming variables: **3148**
  - Total evaluated combinations (solution space): **1,939,168**
  - CPU Solver Time: **20.3 ms**

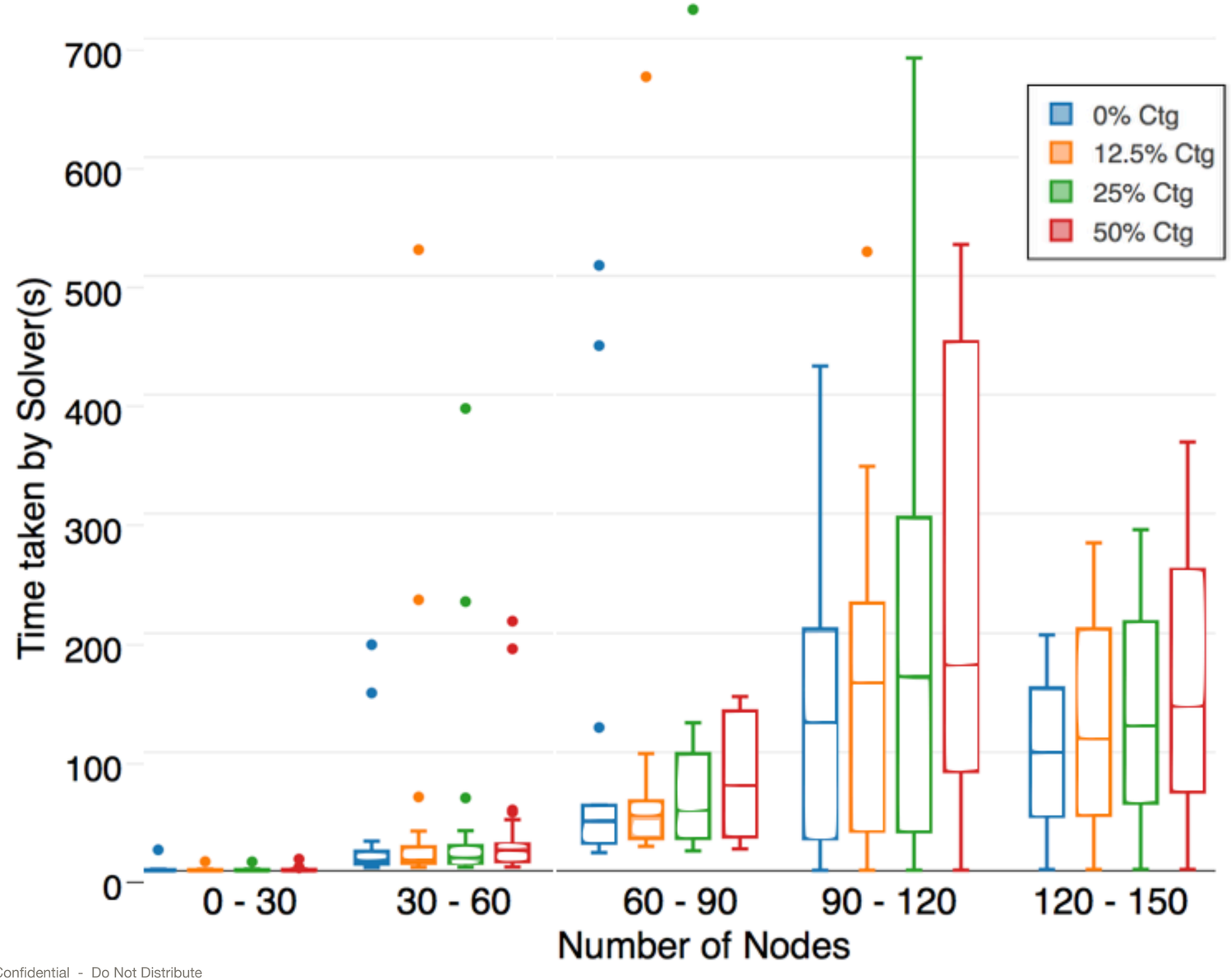
Evaluation: Test Set I



77 Plot Graphs
50% Contingent Events
2 to 5 Narratives running simultaneously
0-3 Resources per event
385 Total problems

Solver:
Gurobi Solver
2.7 GHz Intel Xeon E5 12-Core
64GB RAM

Evaluation: Test Set II



119 Random Plot Graphs
Varied % Contingent Events

Solver:
Gurobi Solver
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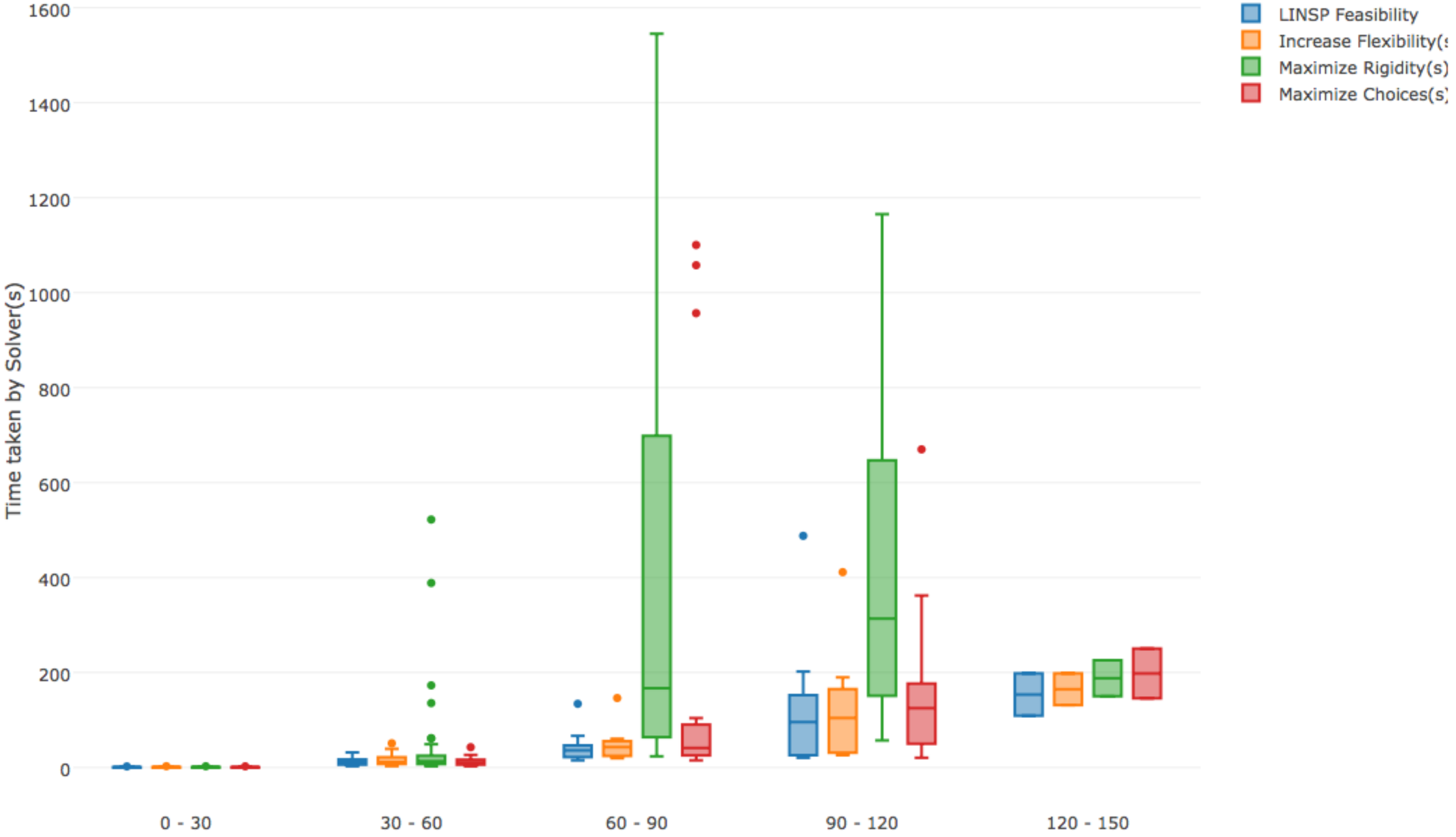
64GB RAM

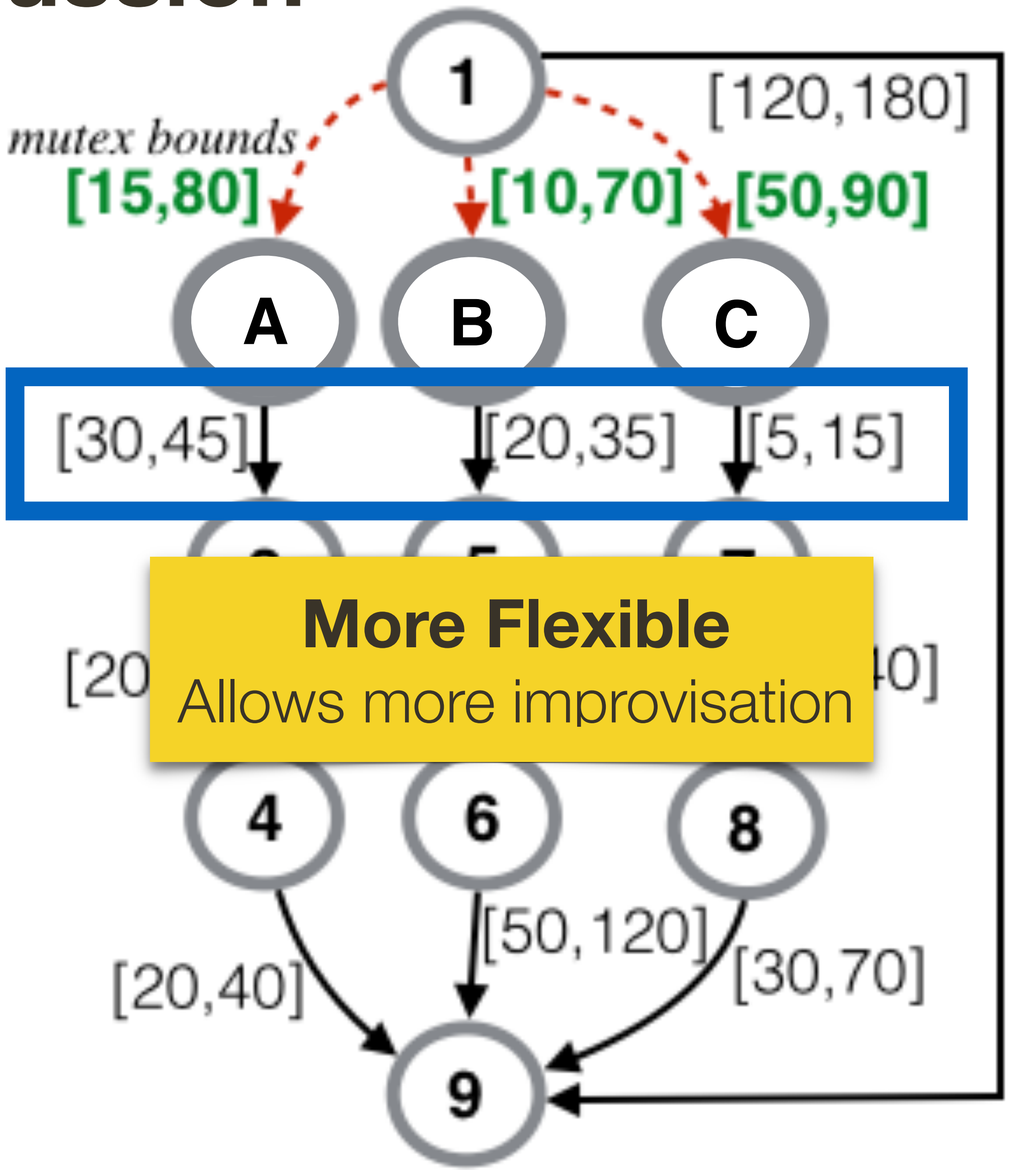
Evaluation: Test Set III

- Narrative Optimisations Tested:
  - LINSP Feasibility Only
  - Maximise Player Choices
  - Maximise Flexibility for Authoring
  - Maximise Rigidity of Requirement Events
  - Reducing Wait Time

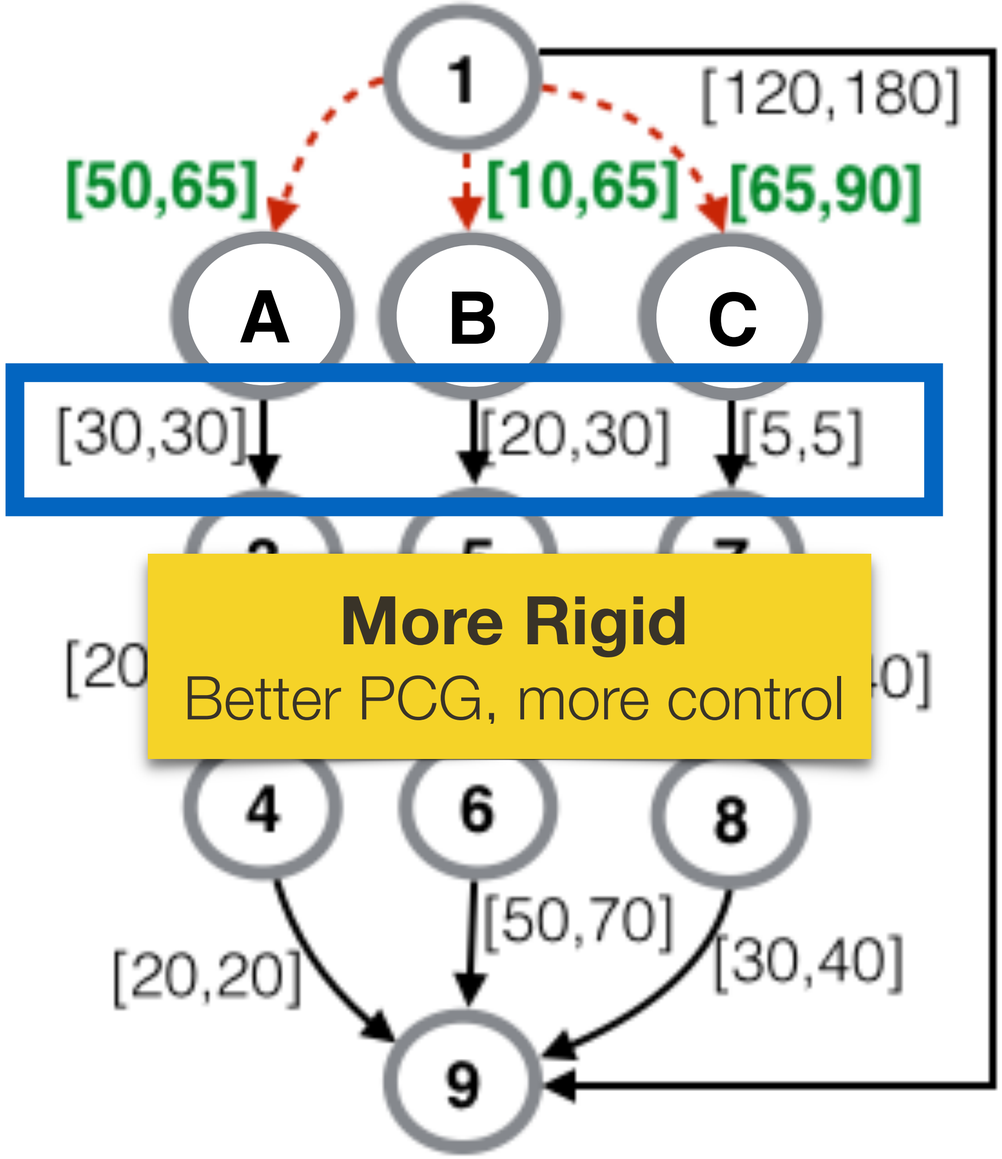
LINSP Evaluation: Test Set III



Discussion



More Flexible
Allows more improvisation



More Rigid
Better PCG, more control

Conclusion

- Identify temporal challenges
- Formulation - temporal uncertainty, resources, plot choices
- Evaluated scalability and feasibility
- Evaluated several optimisation functions

Future Work

- Dataset of narratives bound with temporal durations
- Real time execution
- Mediation

Live Interactive Narrative Scheduling Problem (LINSP) allows for a single designed narrative game to be scaled to account for temporal uncertainty, resources, multiple players and multiple simultaneous instances easily!

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Thank You