A COMPARISON OF ALGORITHMS FOR SOLVING THE MULTIAGENT SIMPLE TEMPORAL PROBLEM

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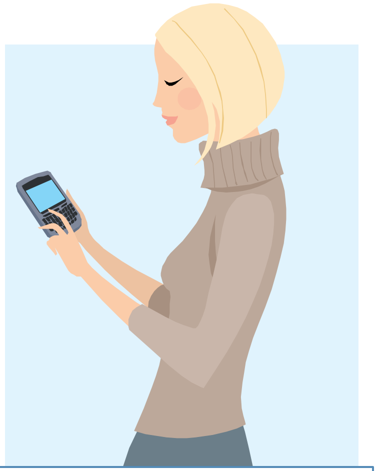
Motivation

- Consider Amy’s agenda:
  - Study for exam
  - Take exam
  - Work on group project
    - Must exchange project deliverables with partner Ben
  - Work on research project

Motivation

- How does Amy choose a schedule for accomplishing her agenda that is compatible with Ben's schedule?
  - Option 1: Ignore Ben
    - Schedule may fail to coordinate with Ben's
  - Option 2: Collect Ben's scheduling commitments / constraints, and choose a compatible joint schedule
    - Ben may not want to reveal private schedule commitments
    - Introduces extra burden on Amy, which grows with every person she coordinates with



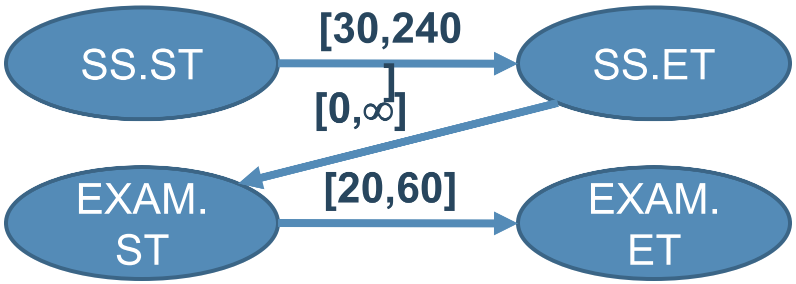
Amy's Agenda:
-Study session (SS)
-Exam
-Group Project (GP)
-Research Project (RP)

Talk Summary

- This talk introduces *multiagent* scheduling algorithms that:
  - Find complete set of ***sound*** joint schedules
  - Exploit the problem's structure and natural distribution across computational agents to ***concurrently*** compute joint schedules and achieve speedup over centralized algorithms
  - Have provable ***privacy*** properties

Background: Simple Temporal Problem (STP)

- A temporal CSP
- Timepoint Variables (V)
  - Represent events
  - Continuous (infinite) domain
- Temporal Difference Constraints (E)
  - Constraints are represented by a bound on the difference between two variables
  - Represented graphically with directed edges



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Extending to Multiagent STP (MaSTP)

- A MaSTP is composed of *n* agent subproblems
- For each agent problem, the set of constraints is composed of intra-agent and inter-agent constraints

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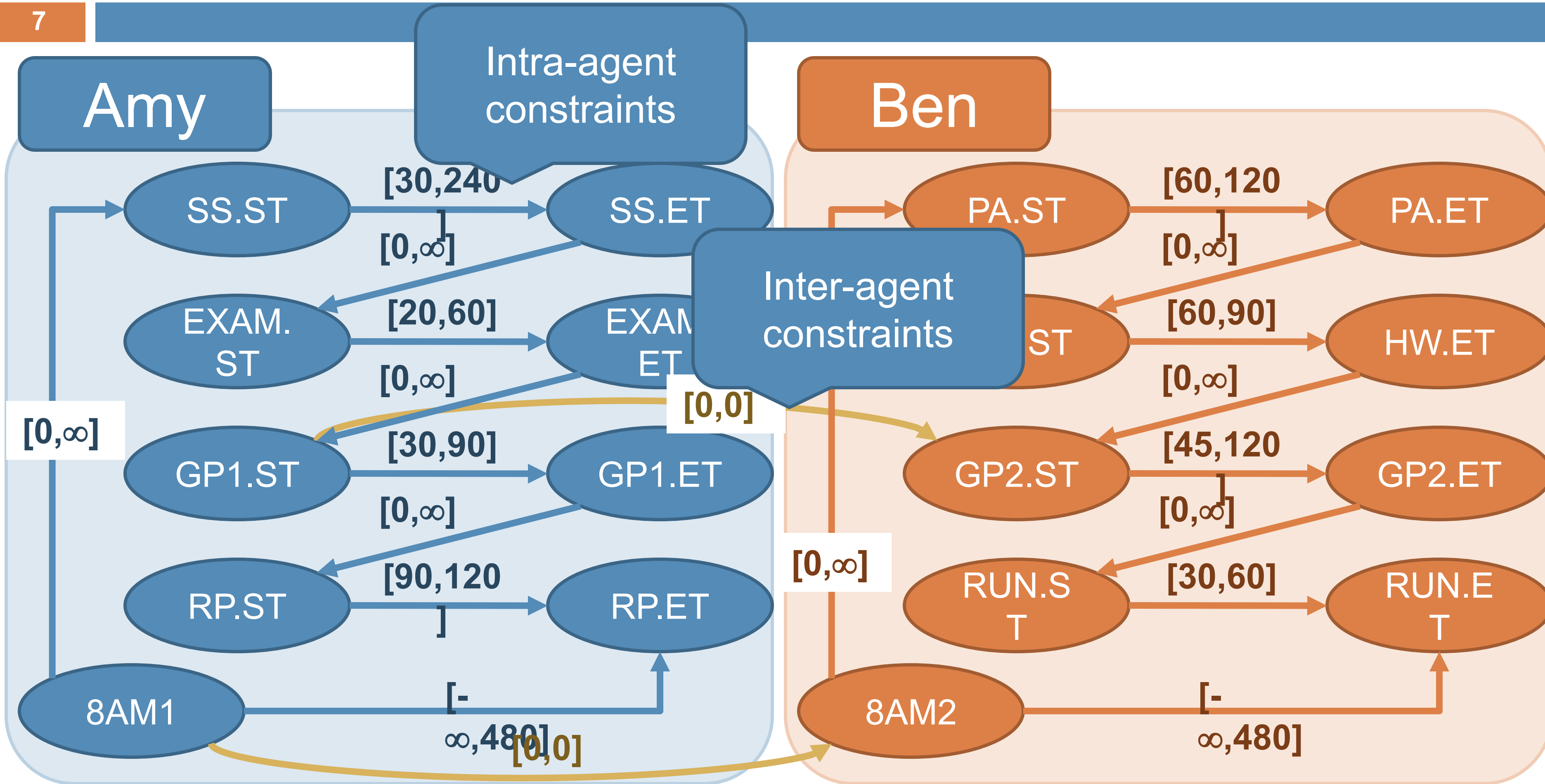
-Exercise(RUN)

Example MaSTP



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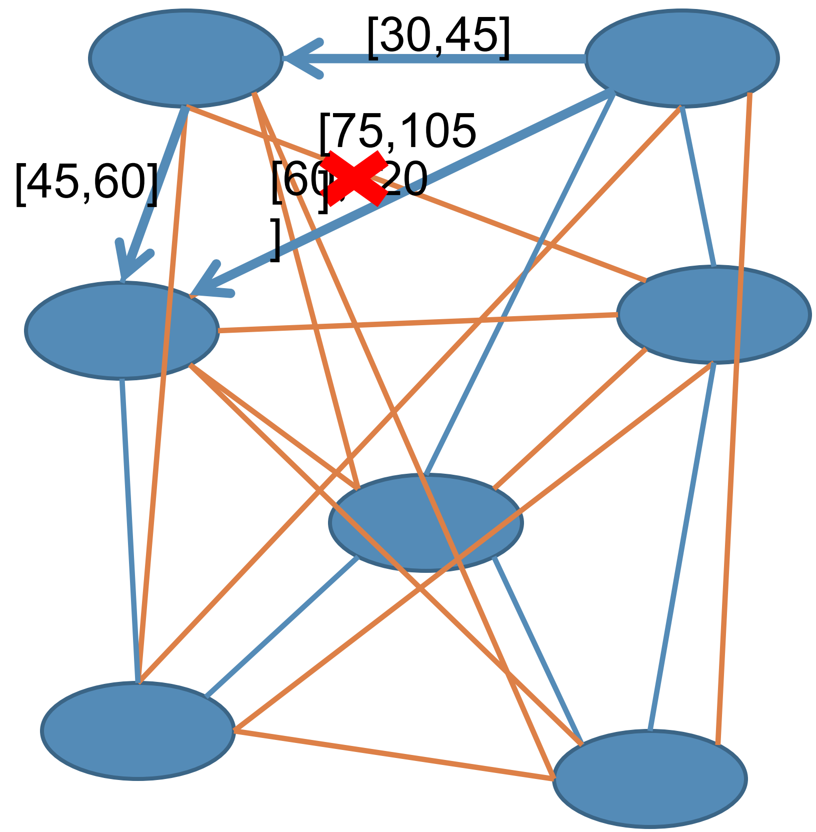
Establishing Decomposability

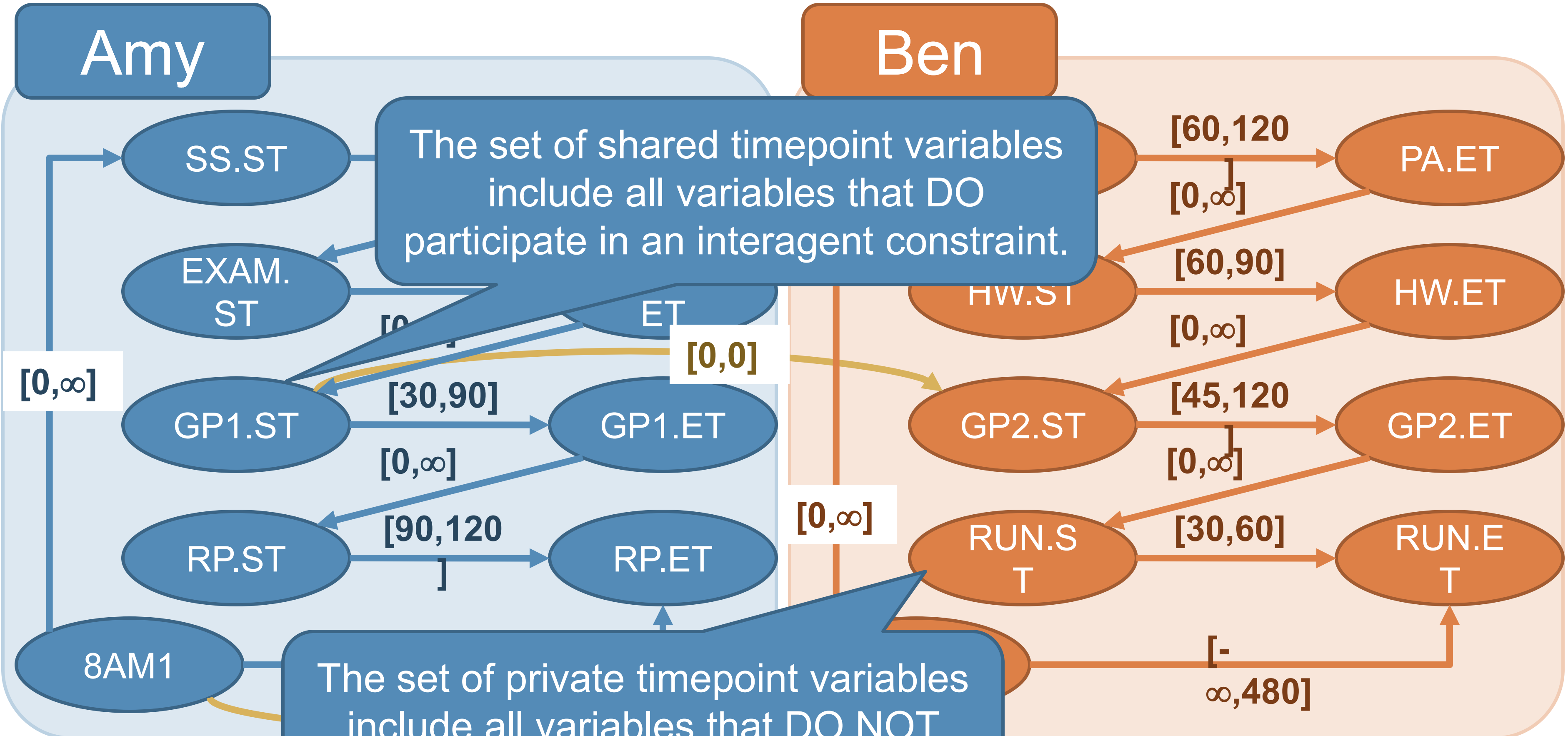
- Decomposable STP:
  - Represents a complete *set* of solutions using ranges of times for each event, where each time can be extended to a sound schedule
- Full Path Consistency
  - All-pairs-shortest-path
  - Calculate min/max time between Amy's study session and Ben's run?
- Partial Path Consistency
  - Step 1: Triangulate graph
  - Step 2: Tighten triangles



Our Approach

- Goals
  - Soundness
  - Concurrency
  - Privacy
- Partition the MaSTP into *n*+1 subproblems:
  - *n* Private STPs: for each agent, the timepoints involved in NO inter-agent constraints, and the constraints involving them
  - 1 Shared STP: the timepoints involved in inter-agent constraints, and the constraints between them

Multiagent STP Partitioning



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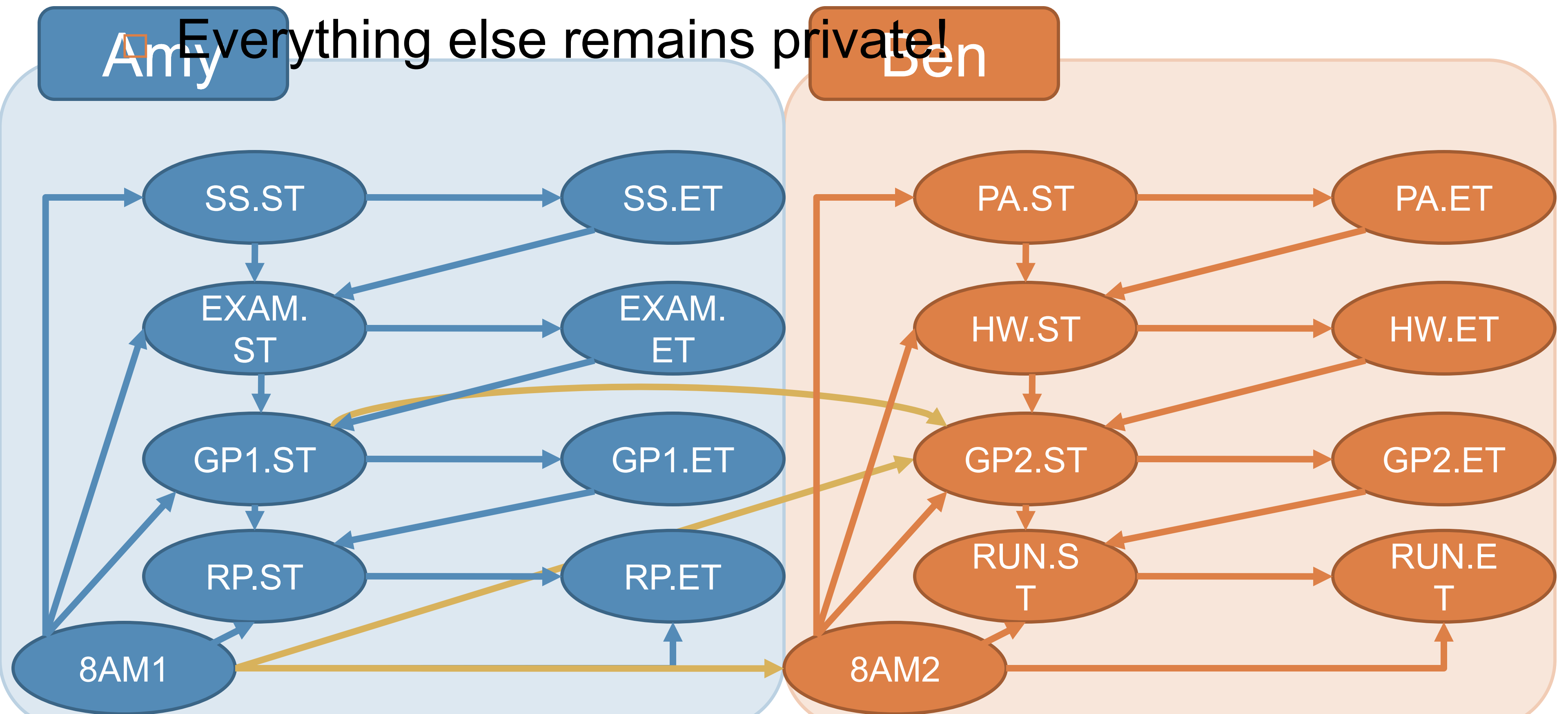
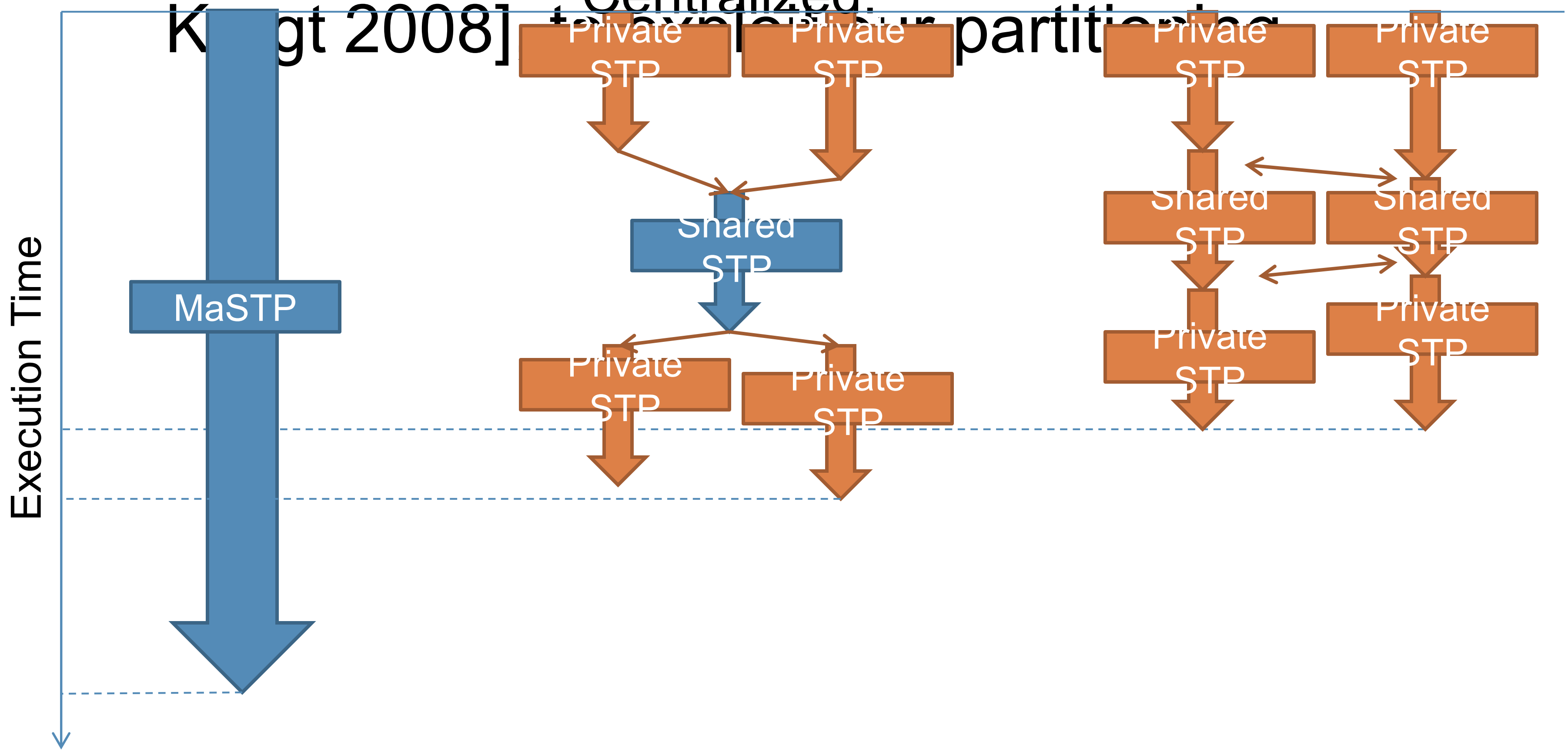
Privacy Properties of our Multiagent STP Algorithms

- The information an agent must reveal to (or conversely learn of) another agent is necessarily limited to the shared STP
- Everything else remains private!

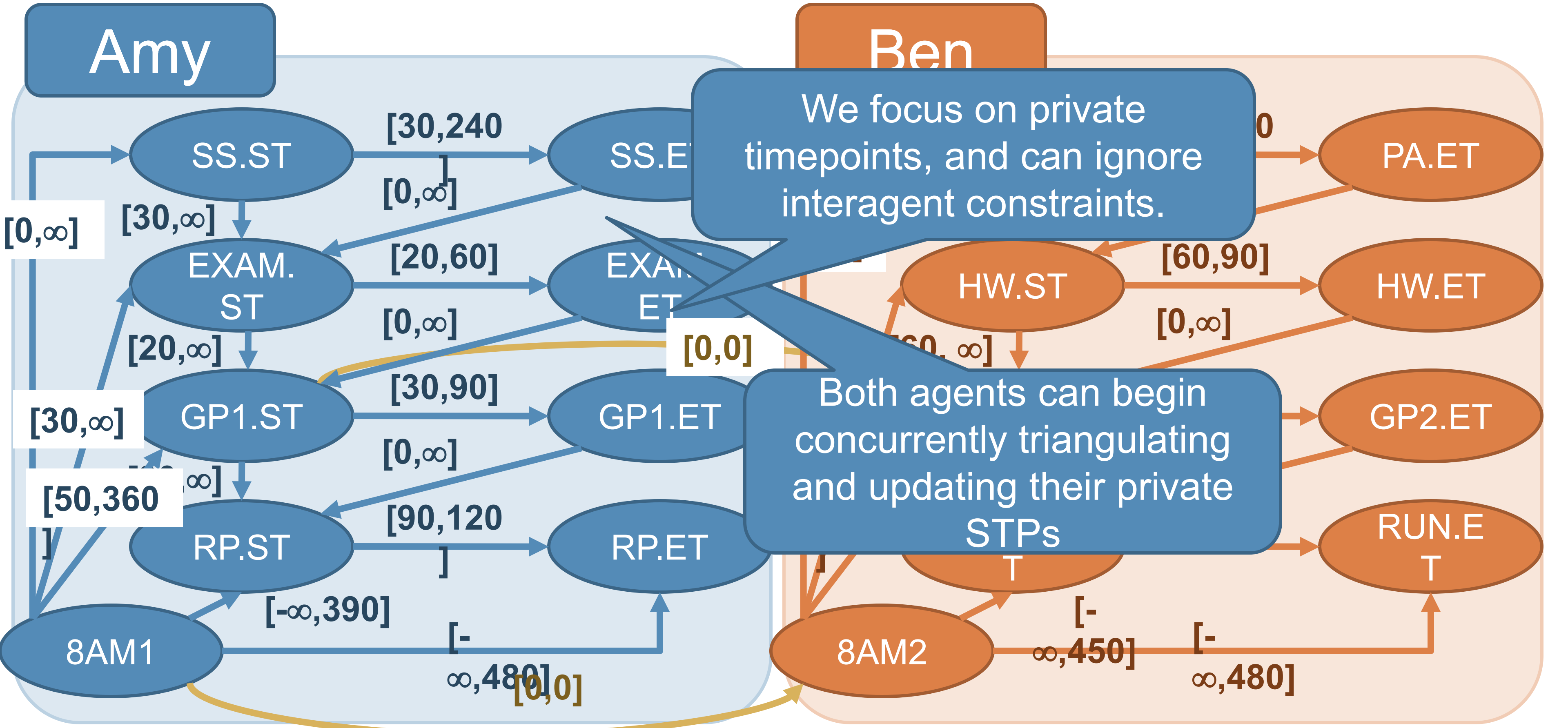


Three Candidate Algorithms

- Adapt state-of-the-art partial path consistency algorithm, P^{3}C [Planken, de Weerdt, van der Krogt 2008] to exploit our partitioning



Partially Centralized: Private1



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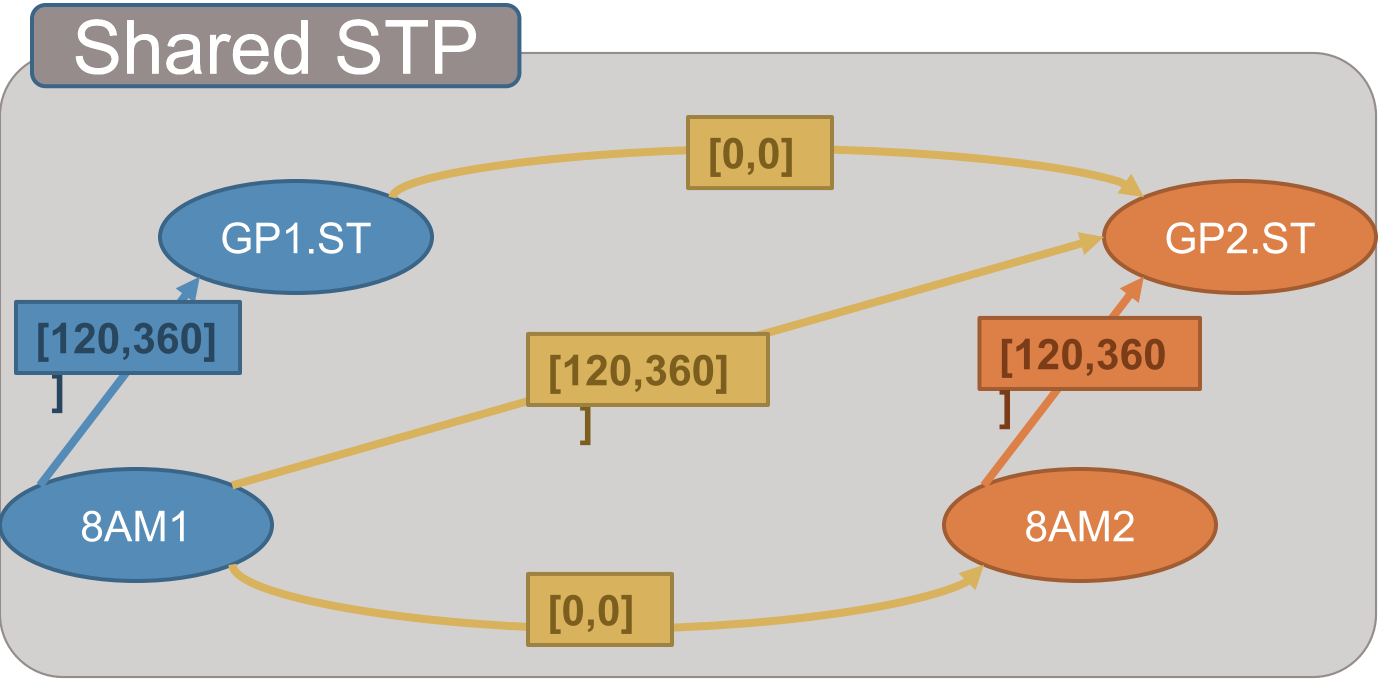
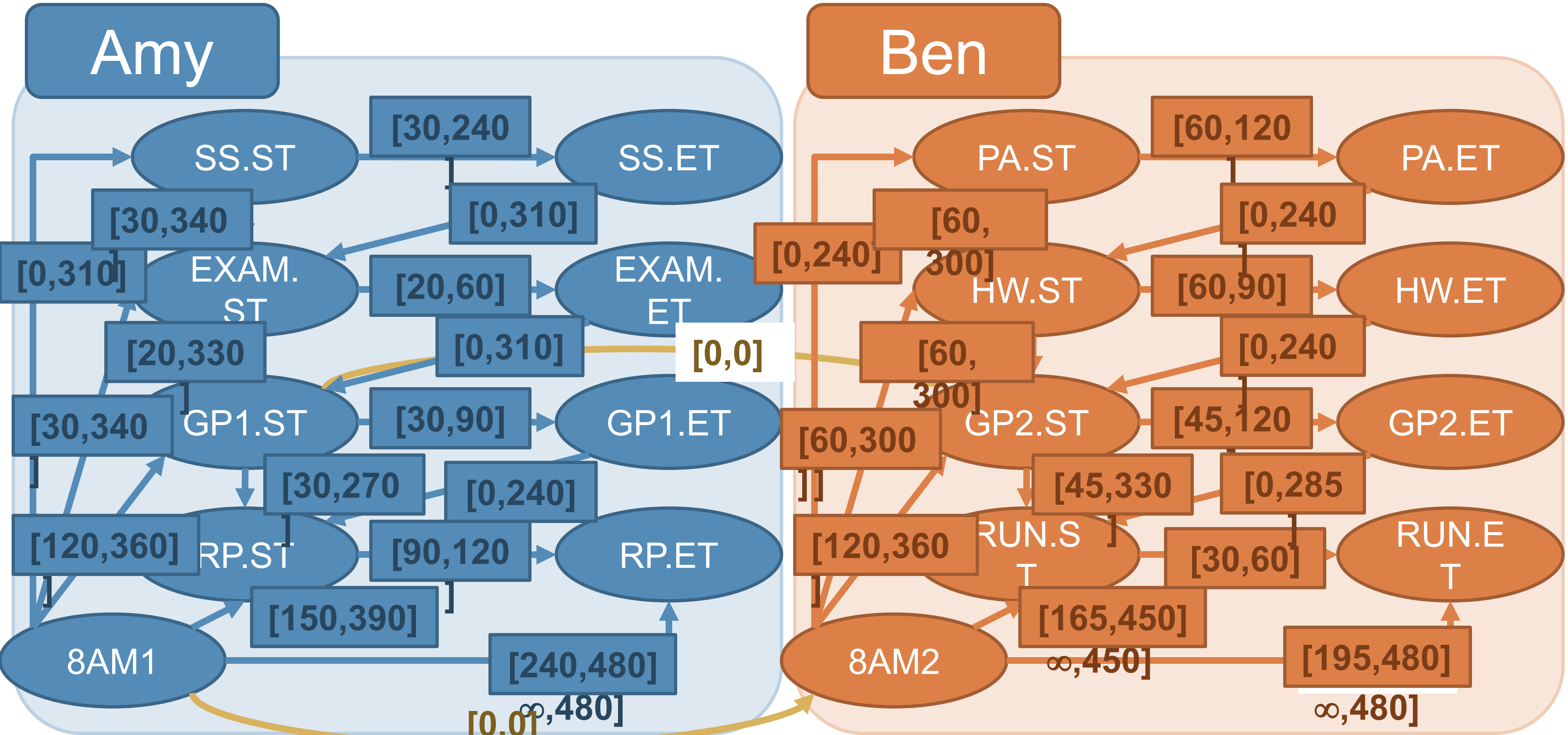
Partially Centralized: Shared



Partially Centralized: Private2



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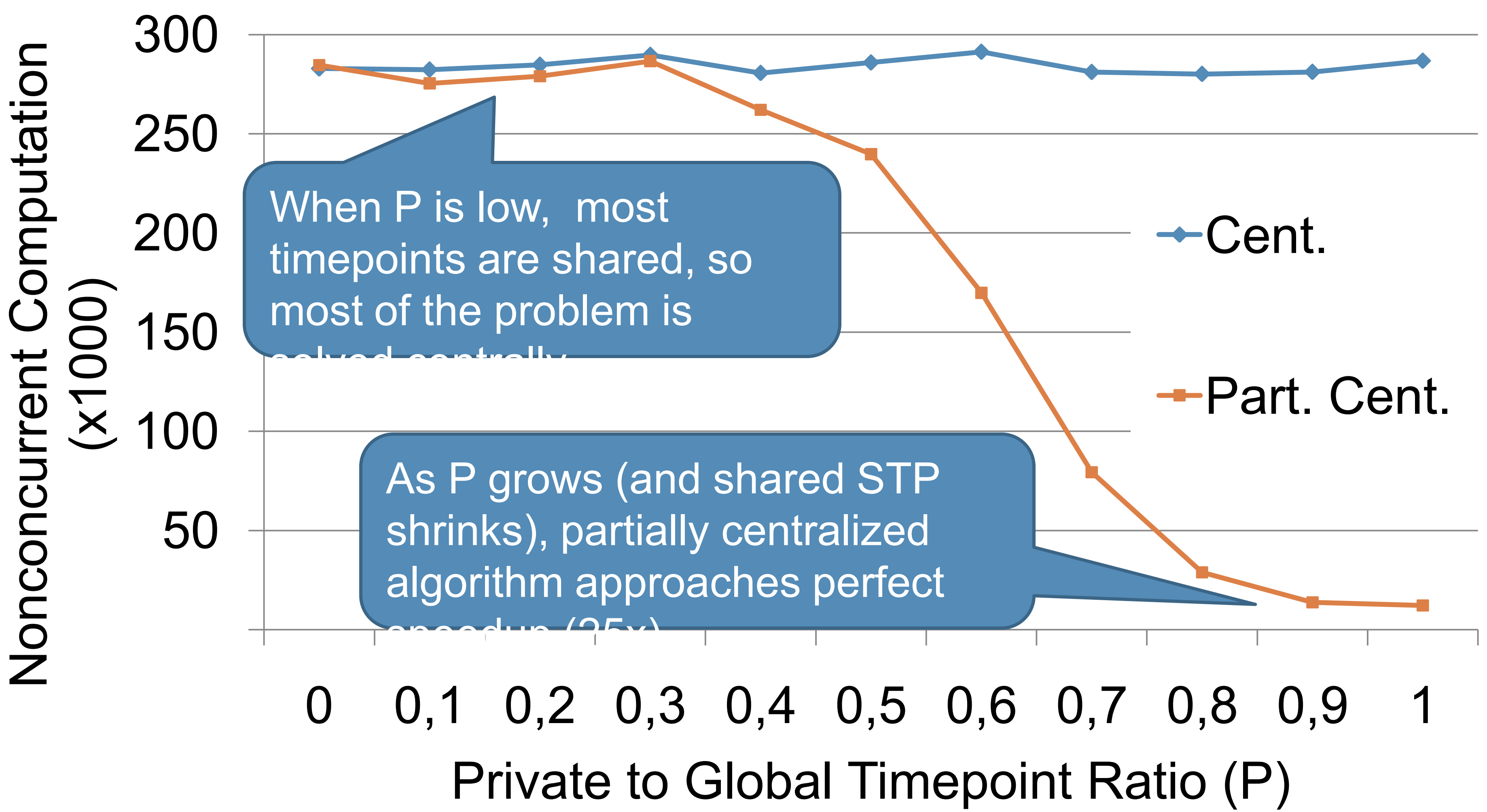
Solving a Multiagent STP: Summary

- 6 constraint checks per triangle
- Total constraint checks (centralized): 132 (22 triangles)
  - Total shared constraint checks: 12 (2 triangles)
  - Total private constraint checks per agent: 60 (10 triangles)
- Partially Centralized approach: 72
- Distributed approach: 66

Empirical Evaluation

- Randomly generated problems with 25 agents, 25 timepoints per agent
- Vary parameter *P* – the proportion of timepoints that are private
- Number of constraints scaled so that centralized computation remains constant
- Record non-concurrent constraint checks (and messages)

Computation: Non-concurrency



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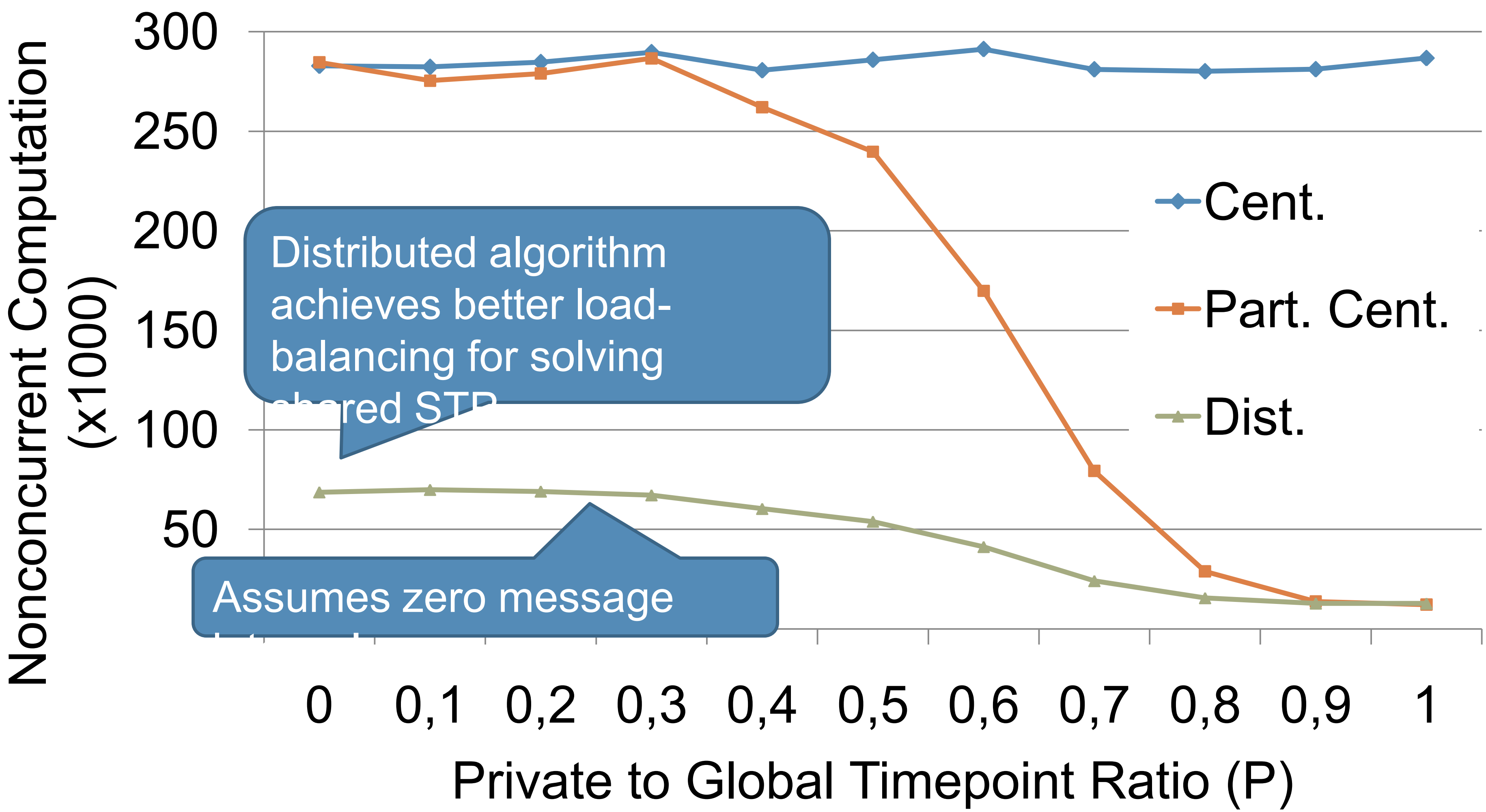

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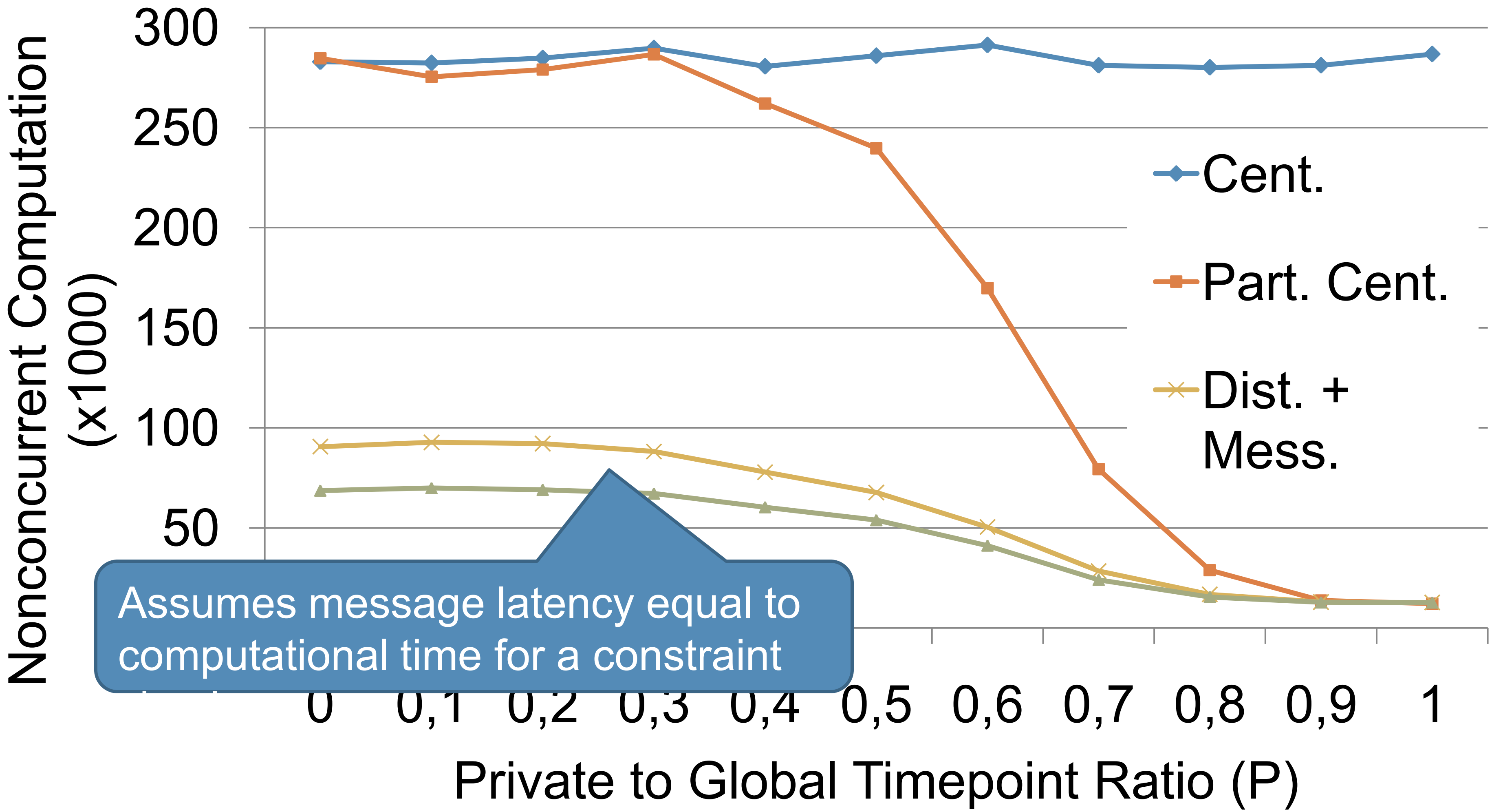

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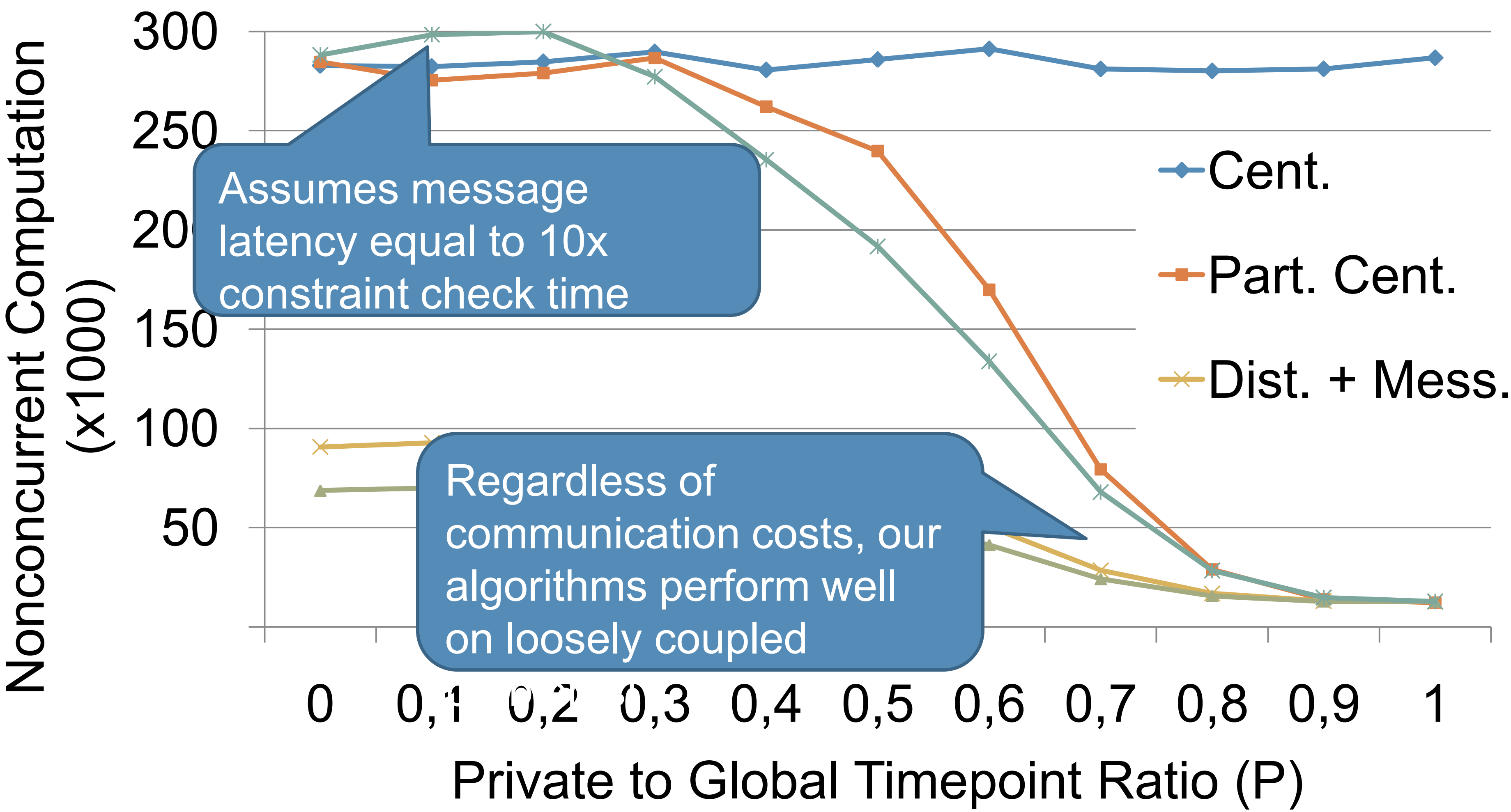

Conclusion

- By exploiting the weakly-coupled structure of multiagent STPs, our partially centralized and distributed algorithms achieve significant solution time speedup through concurrency.
- Our partially centralized and distributed algorithms maintain a high-level of user privacy.
- Exploiting timepoint partitioning information can lead to smaller triangulated graphs (result not shown).
- Future work: Incorporate Multiagent STP algorithms as the foundation for more complex scheduling agents that can coordinate schedules on behalf of users.

Thanks!

- Questions?

References

- Cesta, A., and Oddi, A. 1996. Gaining efficiency and flexibility in the simple temporal problem. In *TIME-96*, pages 45-50.
- Dechter, R.; Meiri, I.; and Pearl, J. 1991. Temporal constraint networks. *Artificial Intelligence* 29 (1-3) pages 61-95.
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- Planken, L.; de Weerdt, M.; and van der Krogt, R. 2008. P3C: A new algorithm for the simple temporal problem. In *ICAPS 2008*, pages 256-263.
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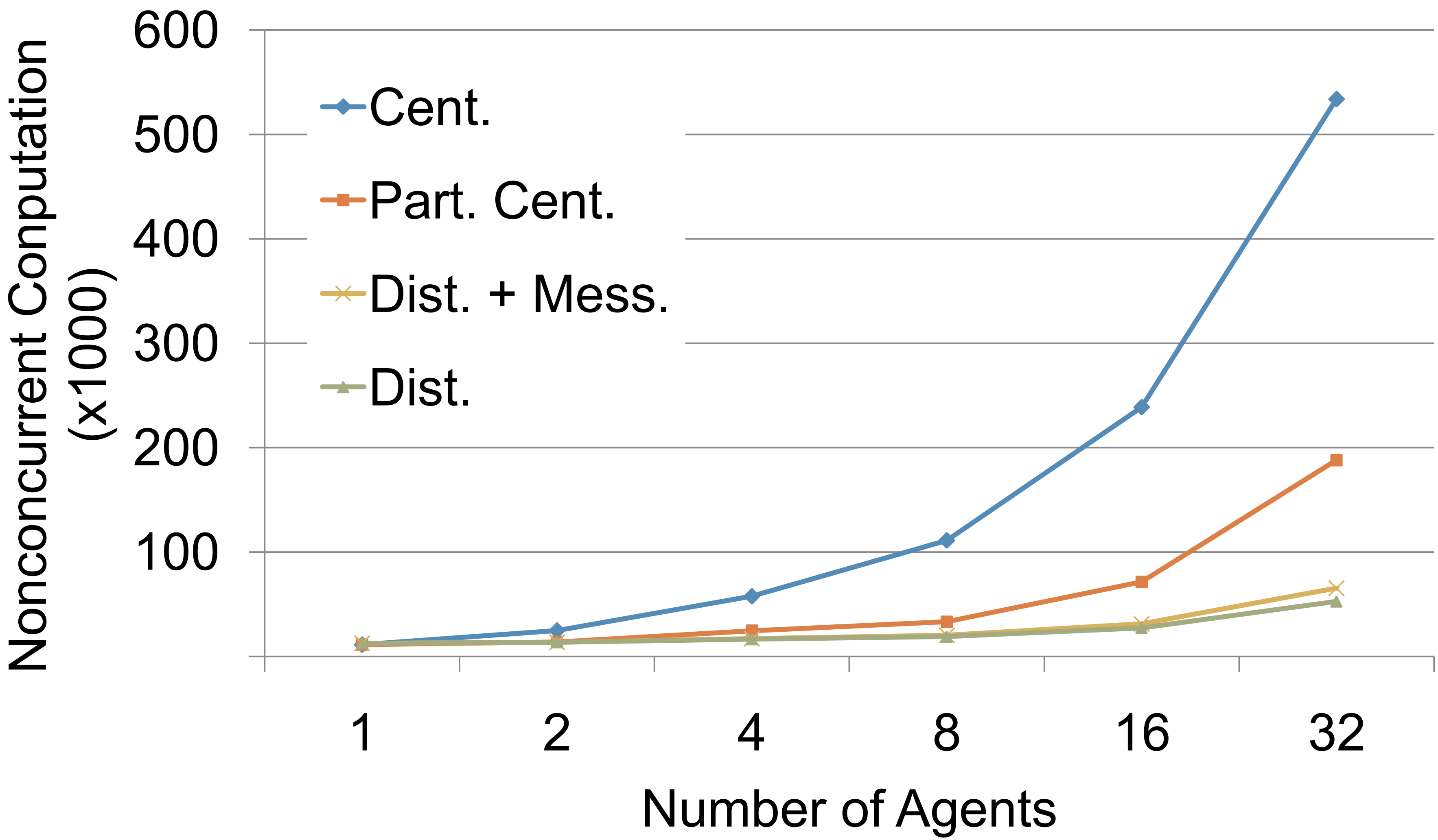
- Xu, L., and Choueiry, B. Y. 2003. A new efficient algorithm for solving the simple temporal problem. In *TIME-ITCL 2003*, pages 210-220.

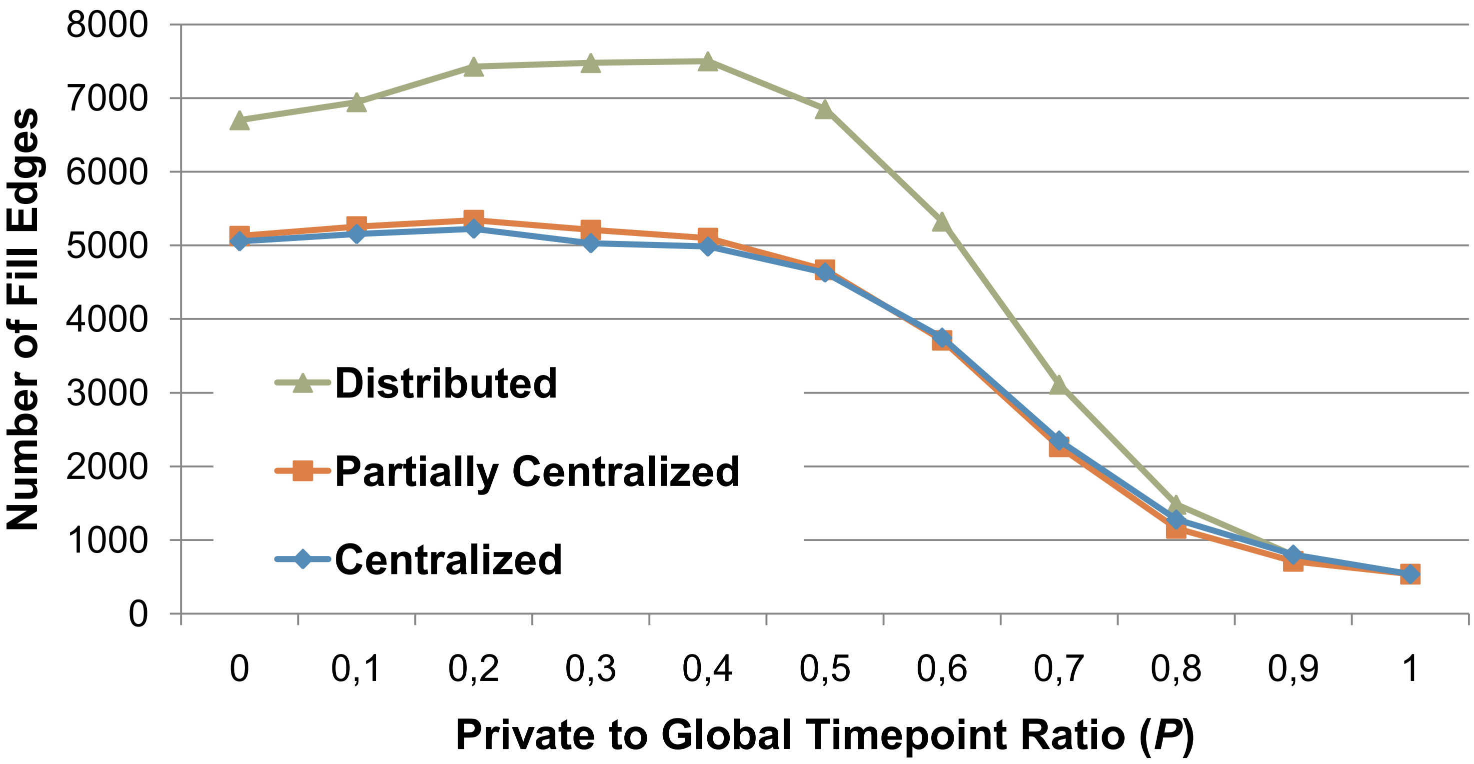
Future Work

- Develop multiagent approaches for solving :
  - Disjunctive Temporal Problems
  - Hybrid Scheduling Problems
  - Preferences
  - Evaluate in a dynamic environment

Computation: Scalability



Number of Fill Edges (triangles)



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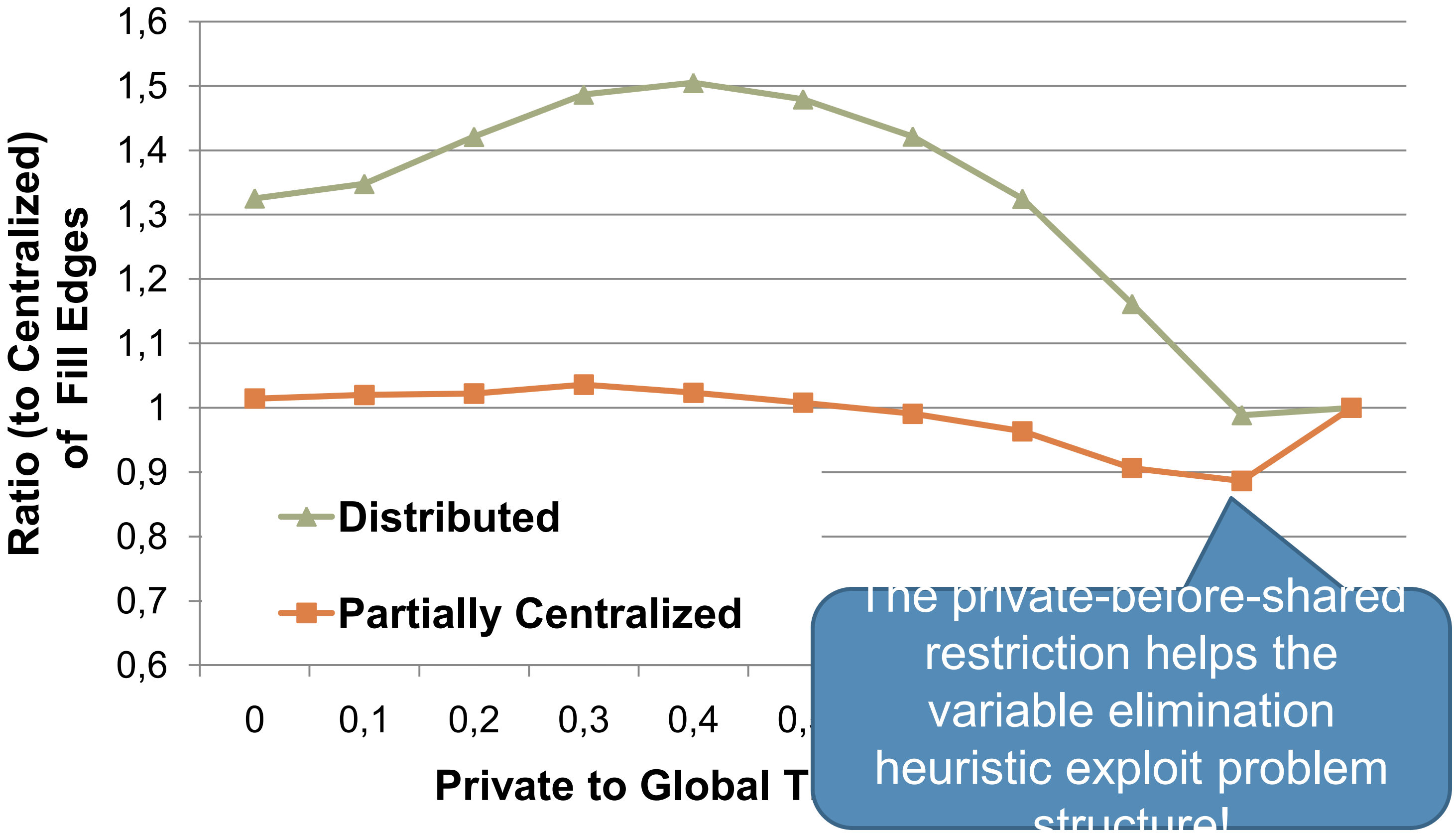
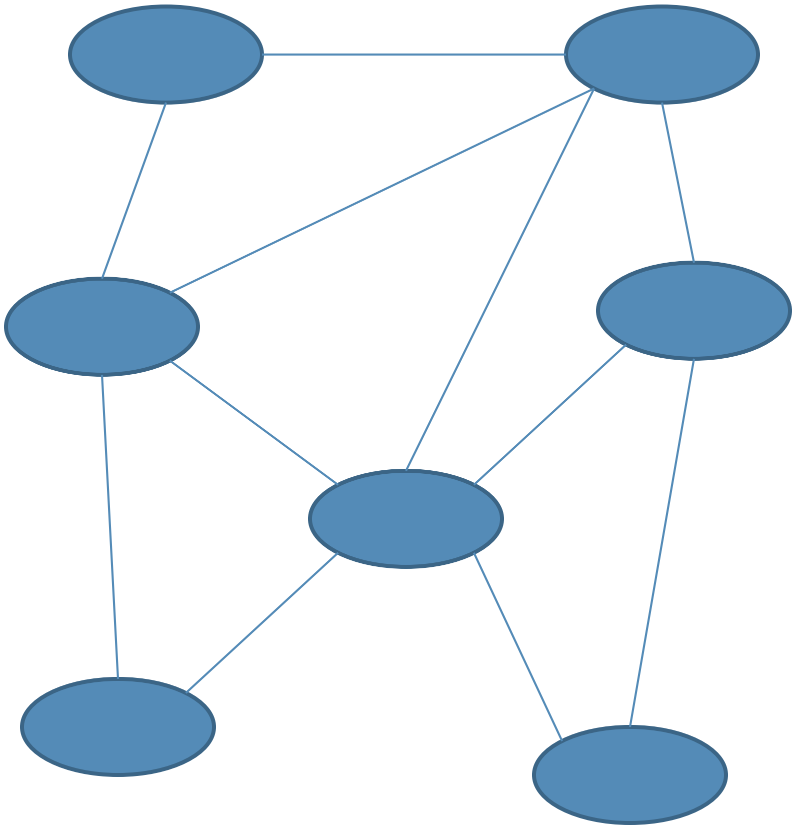


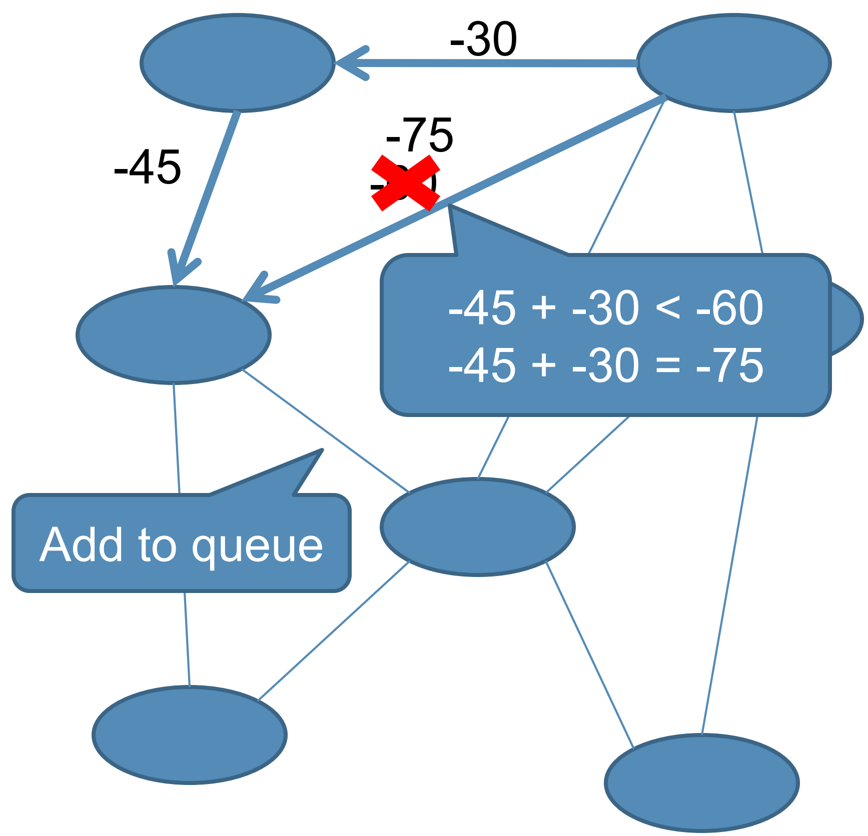
Solving a STP: Partial Path Consistency

- All-pairs-shortest-path
- Step 1: Triangulate
  - Triangulated graph
    - A graph whose largest non-bisected cycle is of size 3
  - Algorithm
    - Remove node
    - Moralize
    - Repeat
  - Try to minimize # of triangles

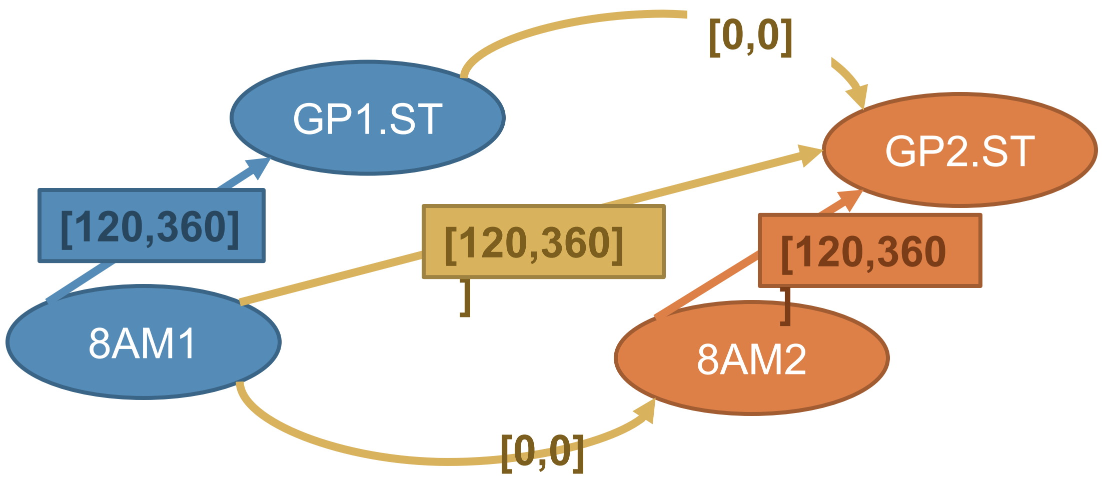


Solving a STP: Partial Path Consistency

- Step 2: Tighten STP
  - Add all Δ's to a queue, Q
  - Until Q is empty
    - Δ = Q.dequeue()
    - Tighten(Δ)
    - Enqueue any affected neighboring Δ

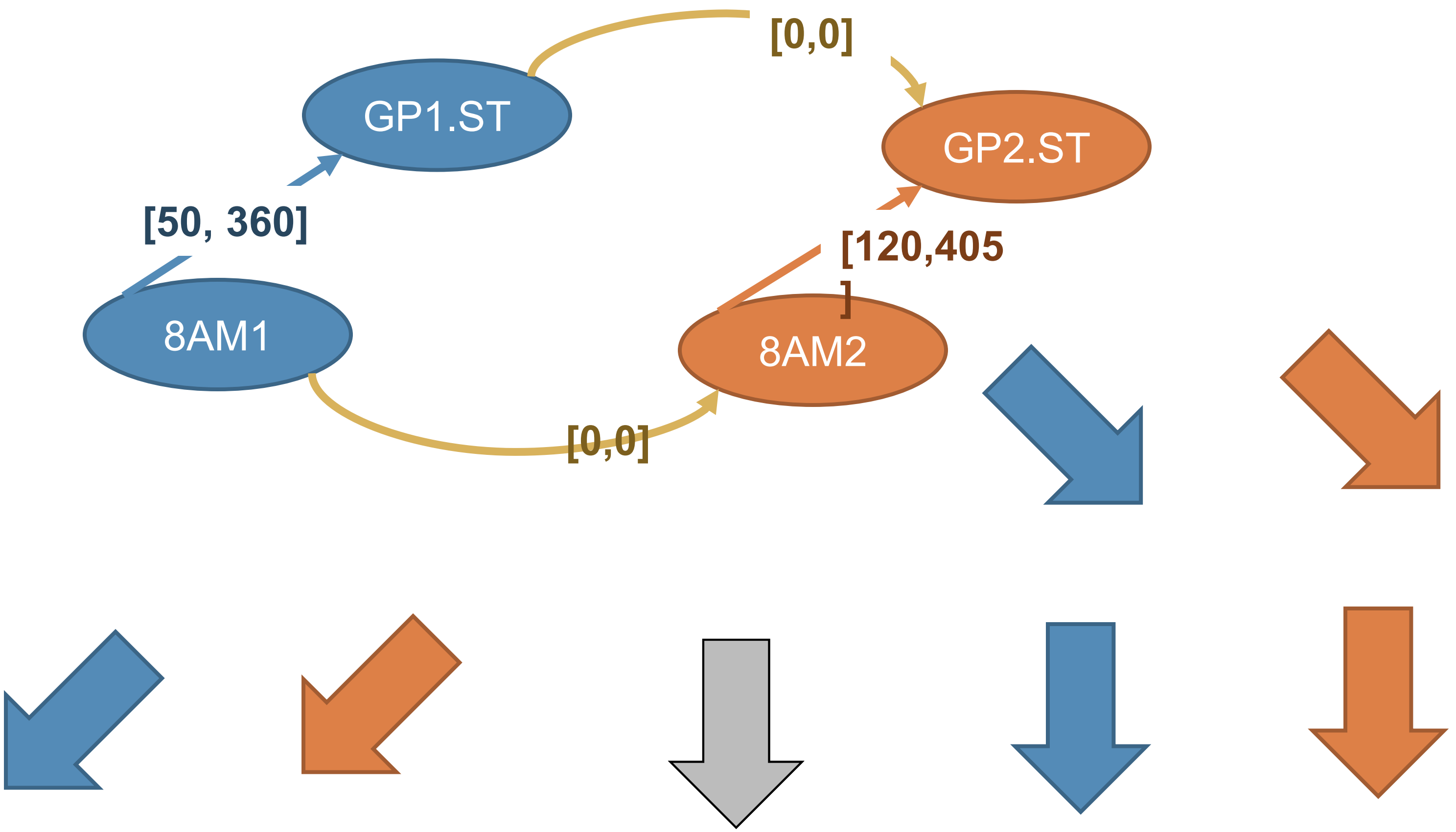


Solving a Multiagent STP: Shared

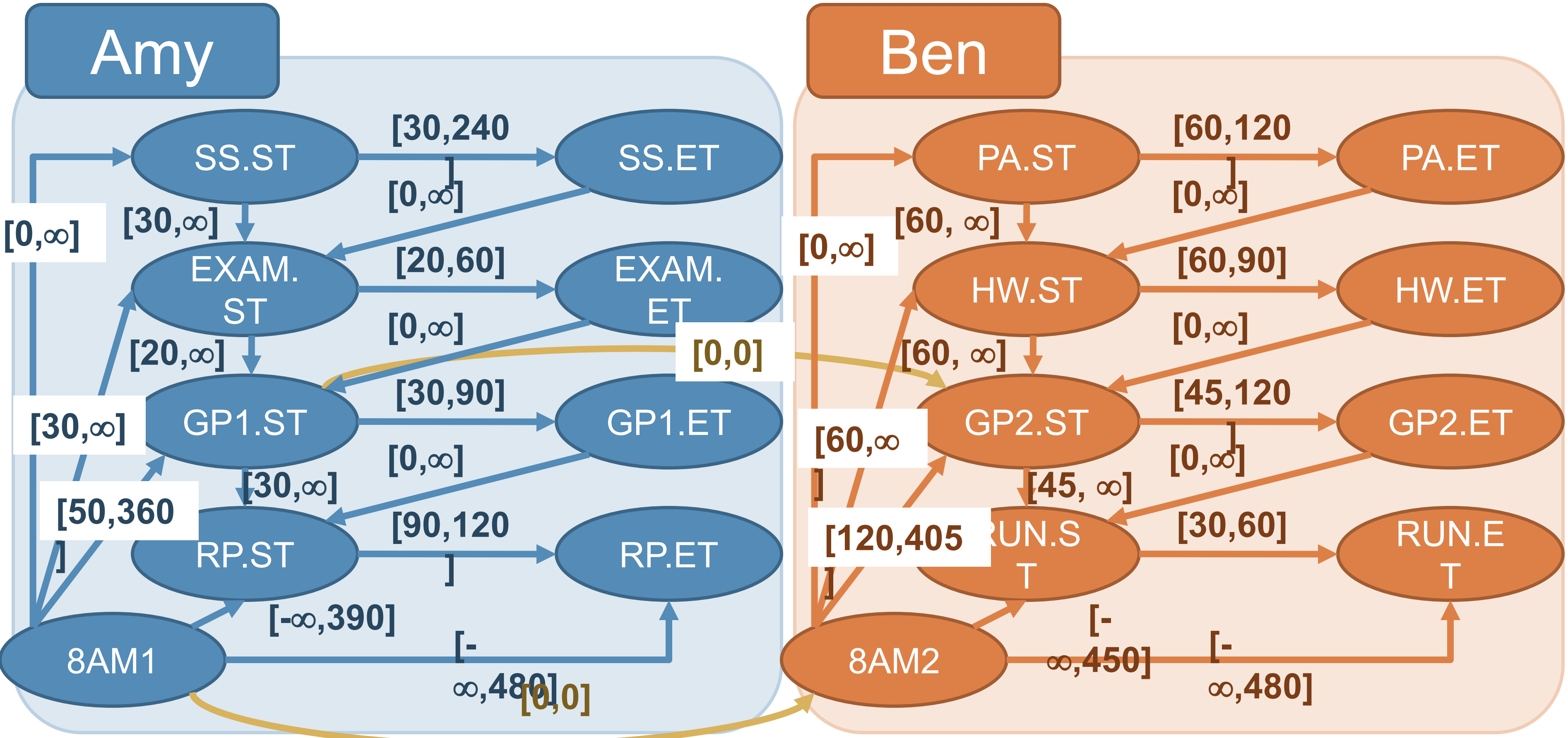


Solving a Multiagent STP: Shared

Shared STP



Solving a Multiagent STP: Private1



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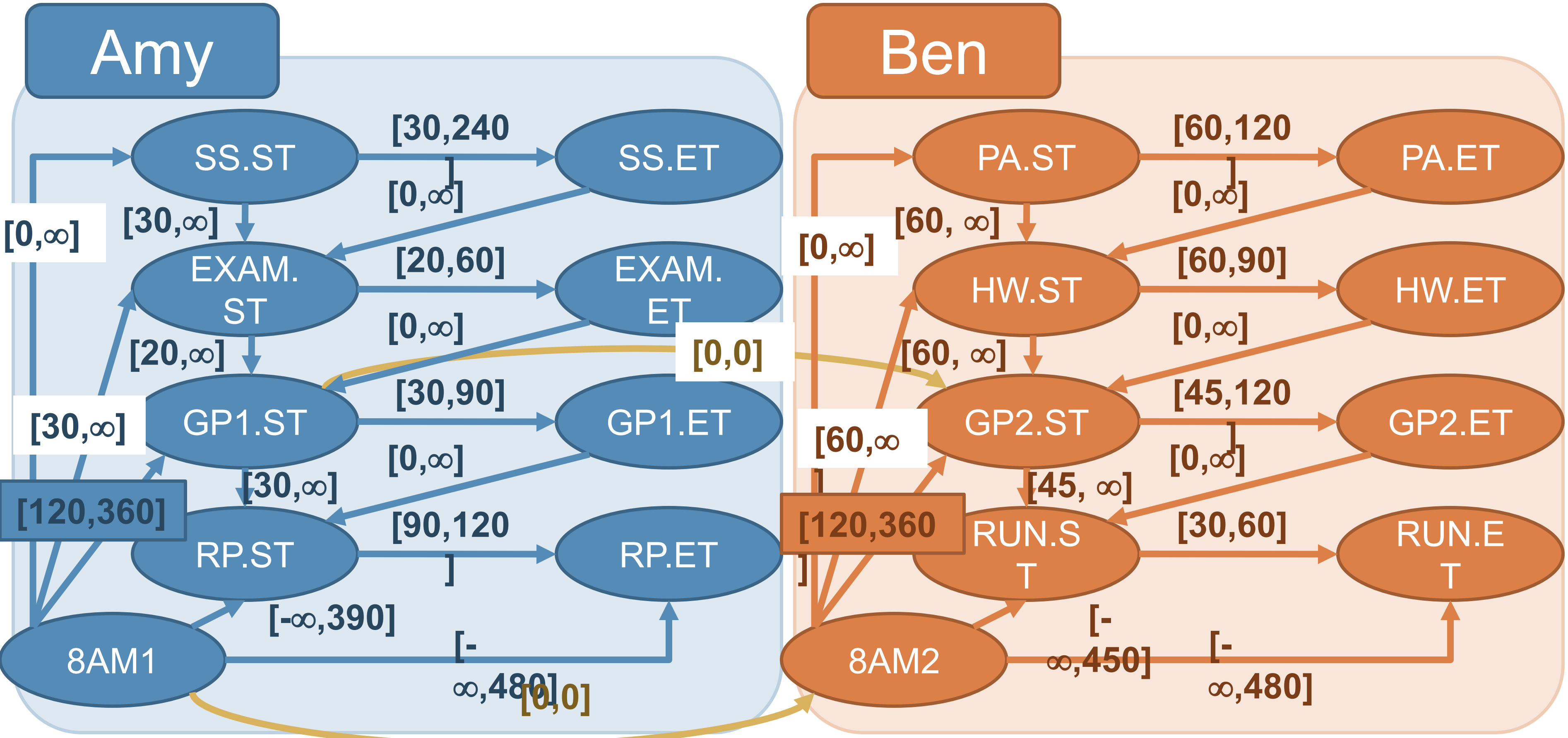

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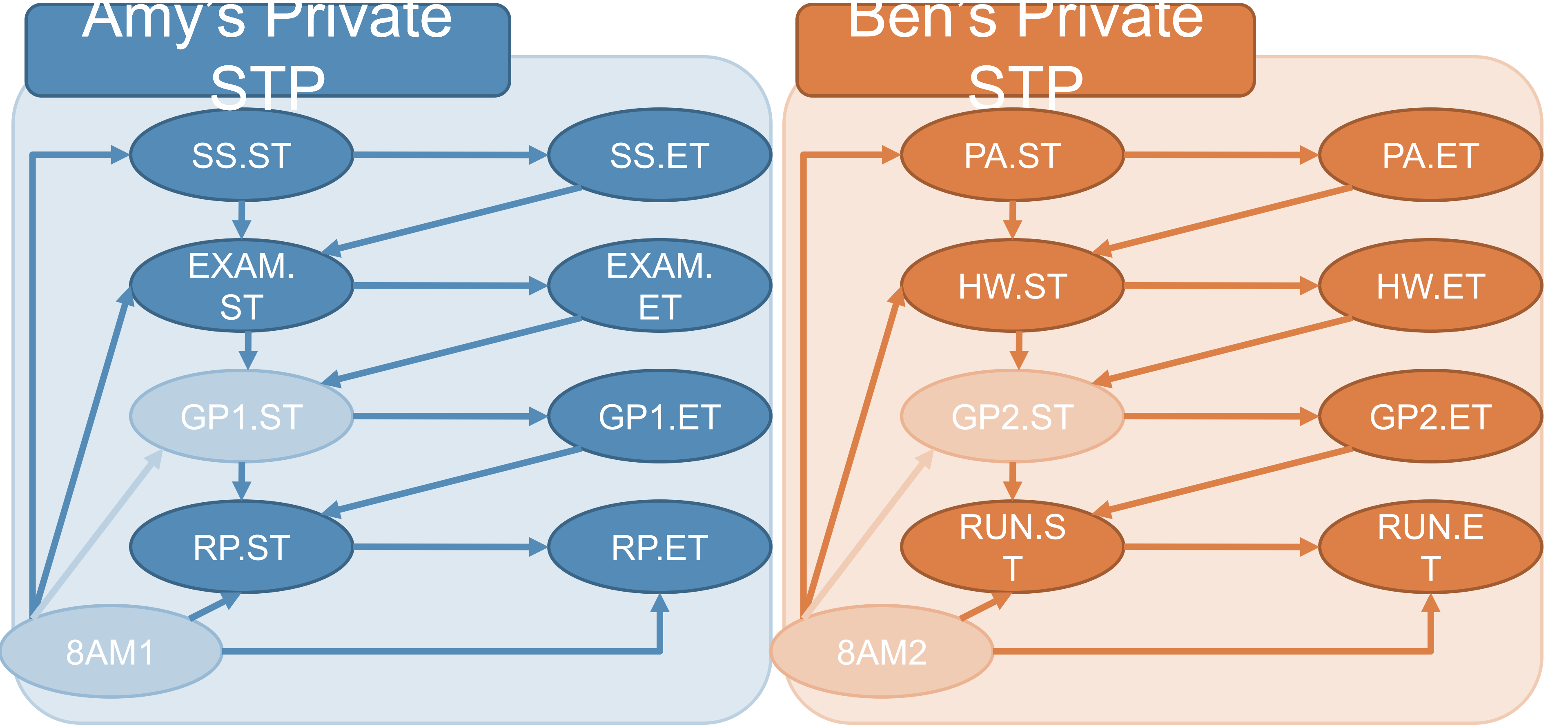
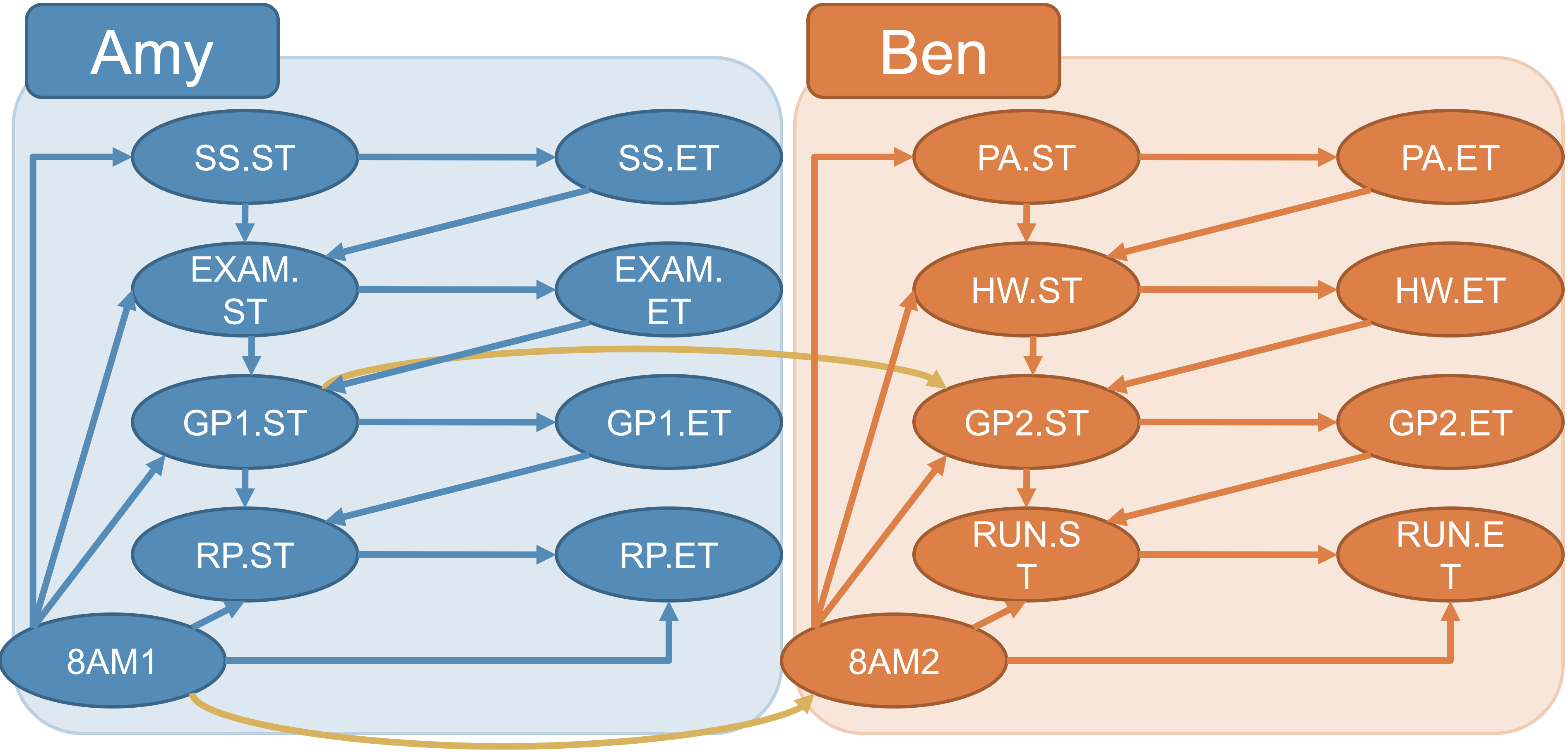
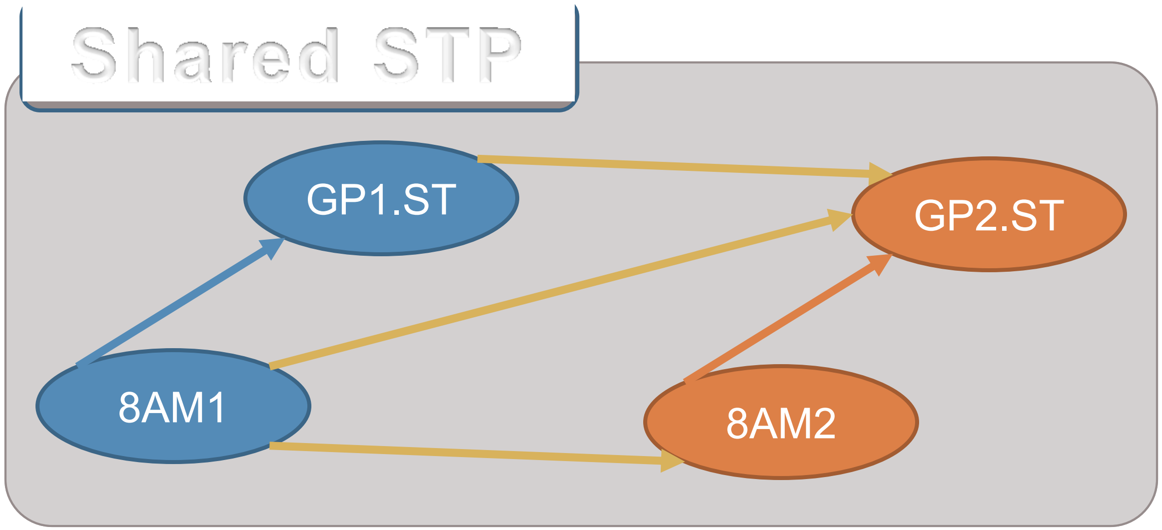
Private STPs



Solving a Multiagent STP: Private2




Shared STP
GP1.ST
GP2.ST
8AM1
8AM2