Tight Bounds for HTN Planning with Task Insertion

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July 31st, 2015

Alternative Title

Theoretical applications of "2^{2^k} Bottles of Beer on the Wall"

Hierarchical Task Network (HTN) Planning

HTN planning is the problem of decomposing an initial task to accomplish into a sequence of executable steps.

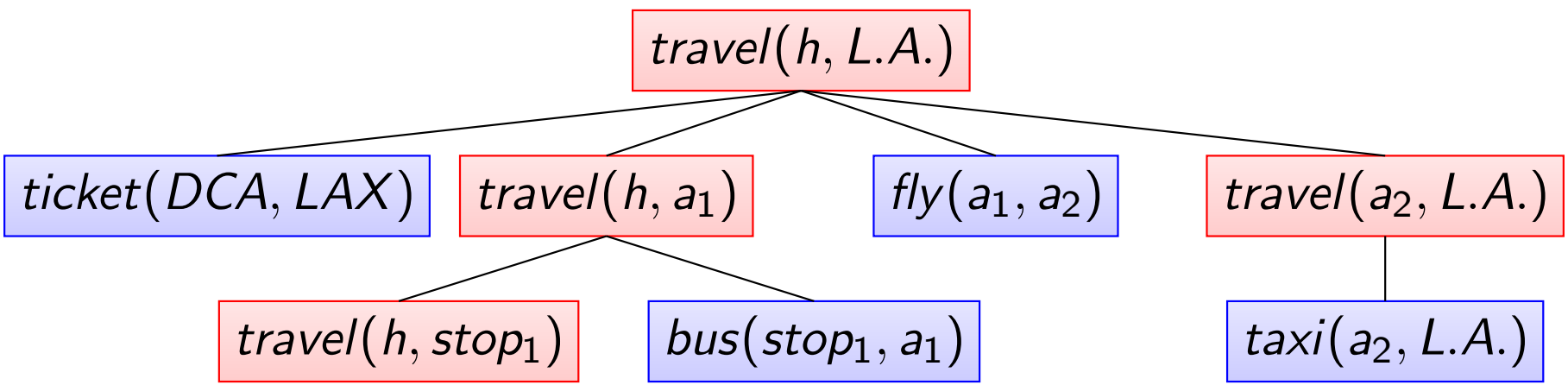
- Encoding control knowledge for planning
  - Agent planning in robotics and simulation: ARTUE (2010), Johnny (2012)
  - Planning and mission generation for games: KILLZONE 2, Elder Scrolls, Armed Assault
- Representing and planning with processes and hierarchies
  - Composing web services (Sirin, 2004; Tang 2013; others)
  - Program configuration (Soltani, 2012)

Source: Fraunhofer

HTN Planning (Overview)

The purpose of HTN planning is to complete a task. Tasks are either:

- Primitive, which corresponds to some concrete action we know how to perform, e.g., $walk(room, hall)$, or $drink(coffee)$
- Non-primitive, which is an abstract task. E.g. $travel(home, L.A.)$
- Must recursively decompose non-primitive tasks until we get primitive tasks we know how to execute directly
- We are given a set of methods, which are recipes on how to accomplish abstract tasks. E.g., to travel from *home* to *L.A.*, we might decompose as follows:



Methods and Decomposition

- A method (t, tn) is a non-primitive task t paired with a network tn

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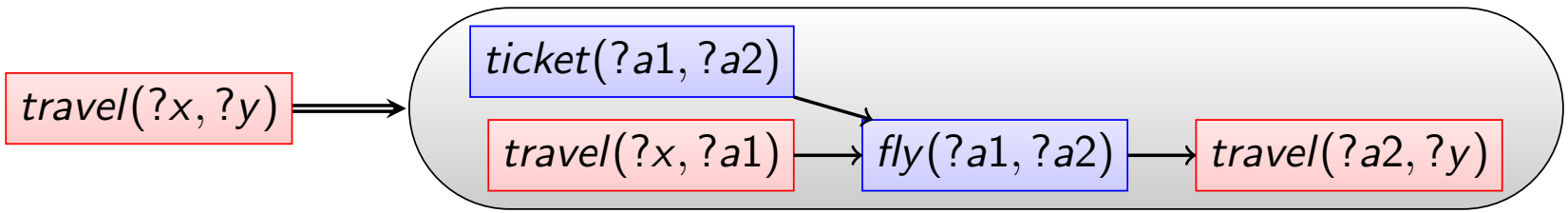

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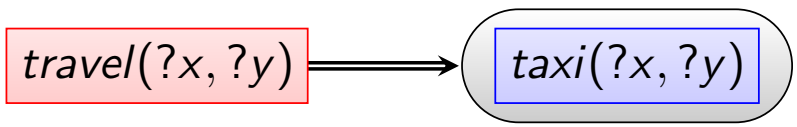

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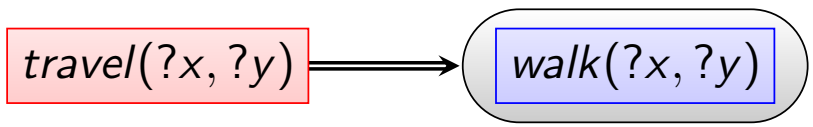

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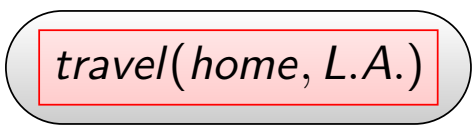

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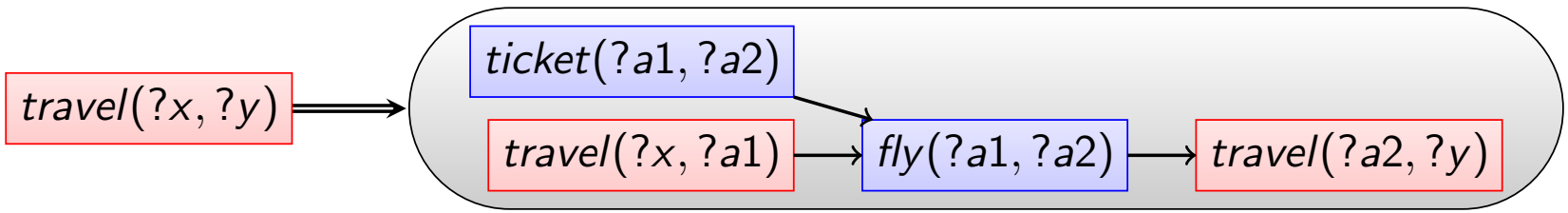

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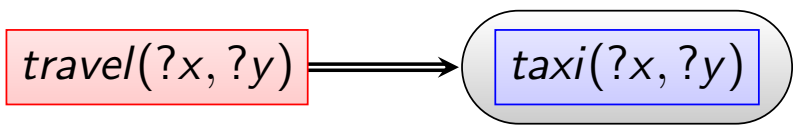

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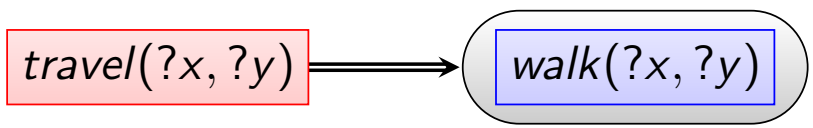

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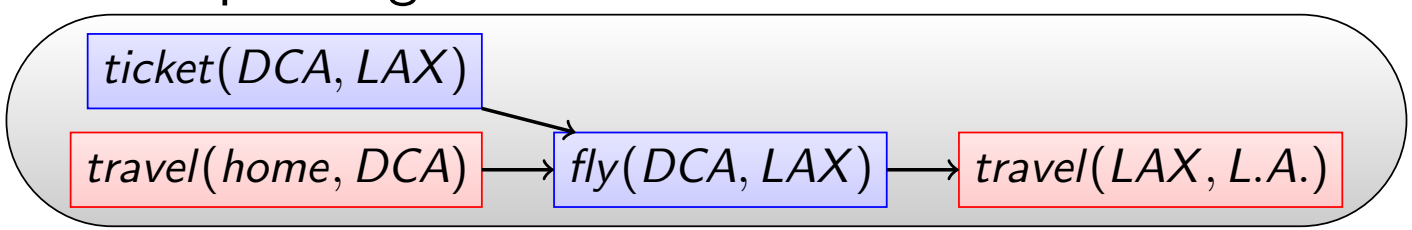

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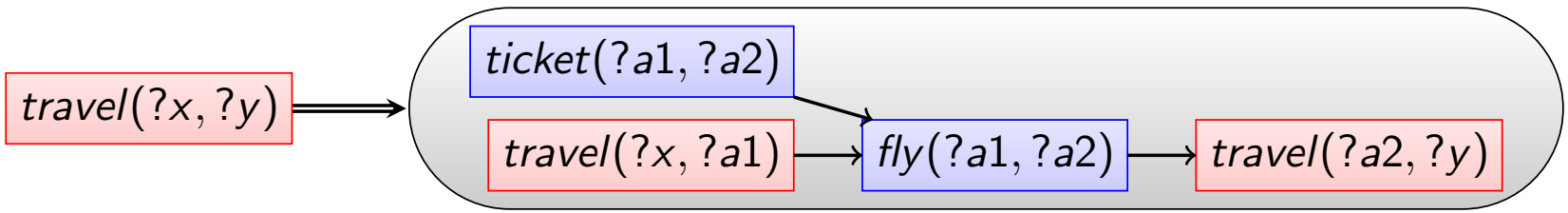

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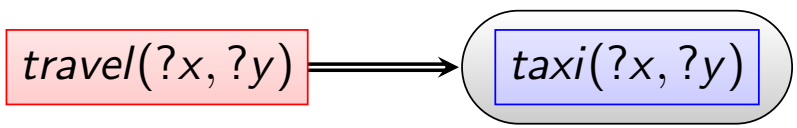

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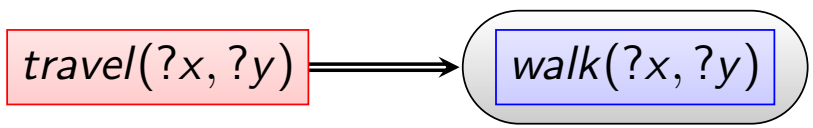

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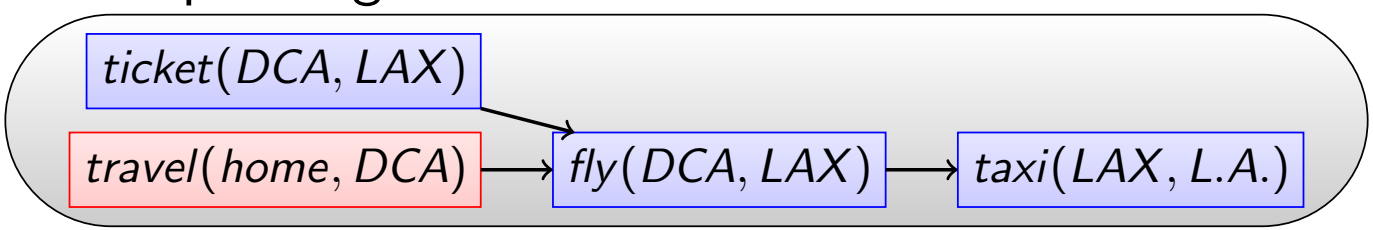

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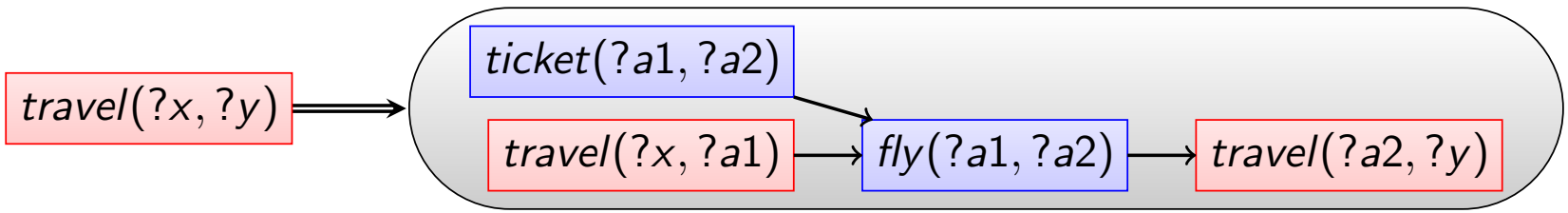

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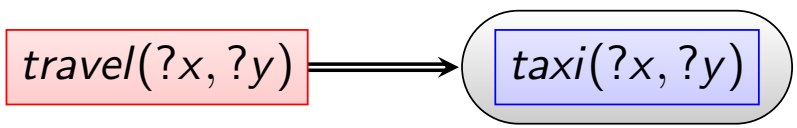

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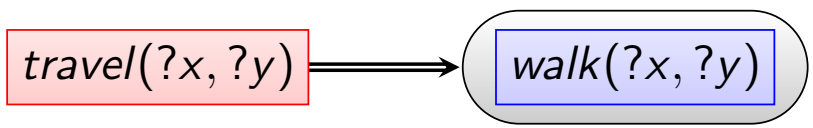

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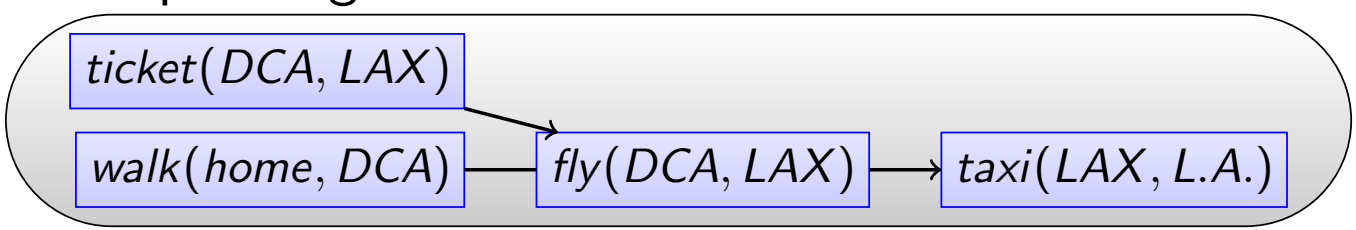
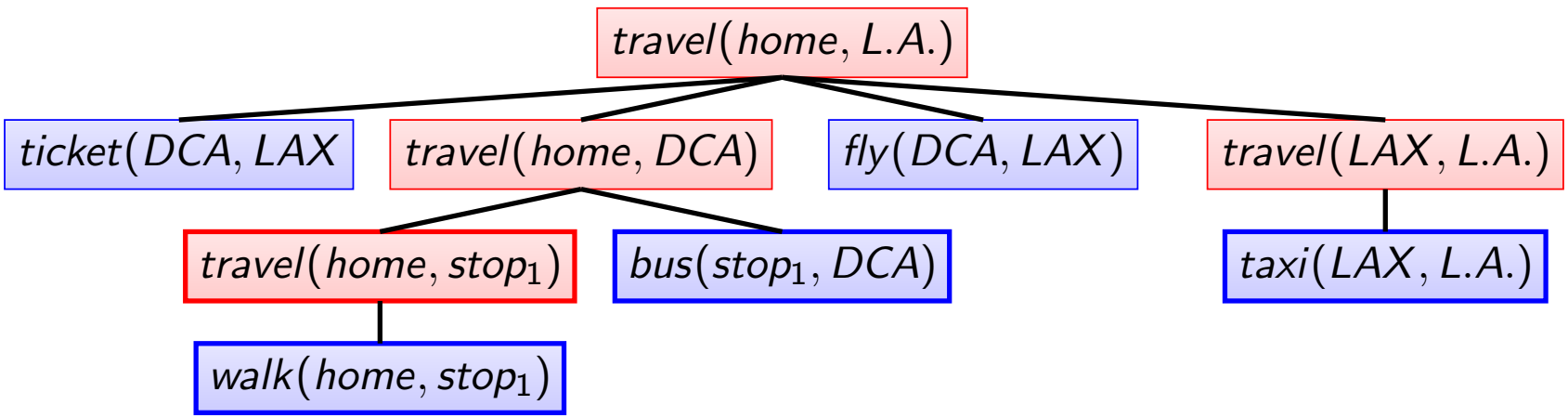


Replanning with HTNs



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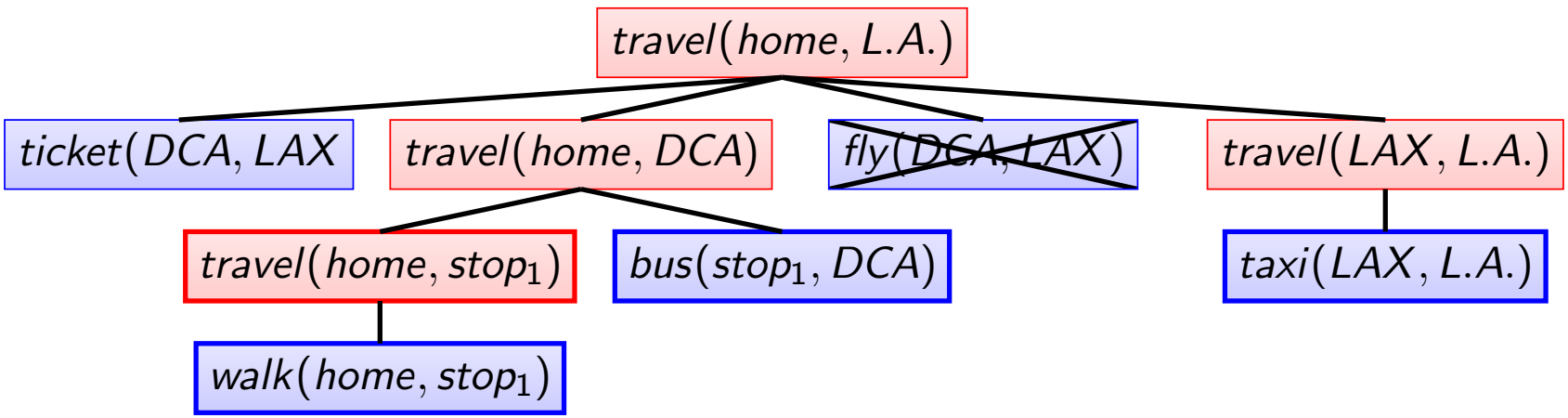
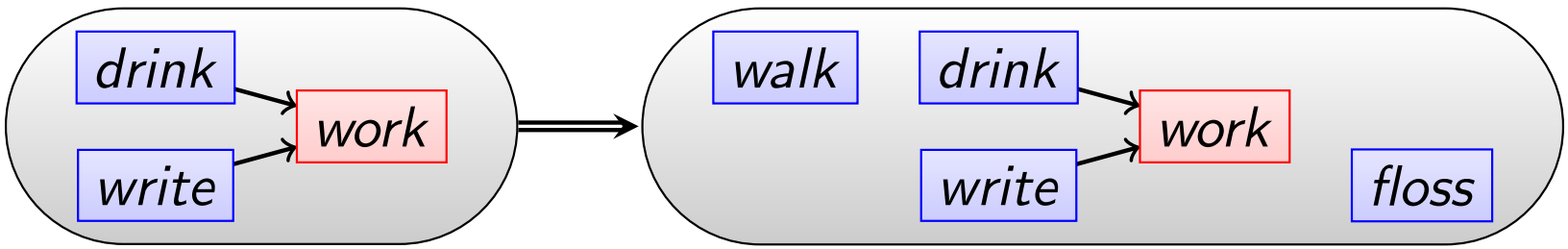


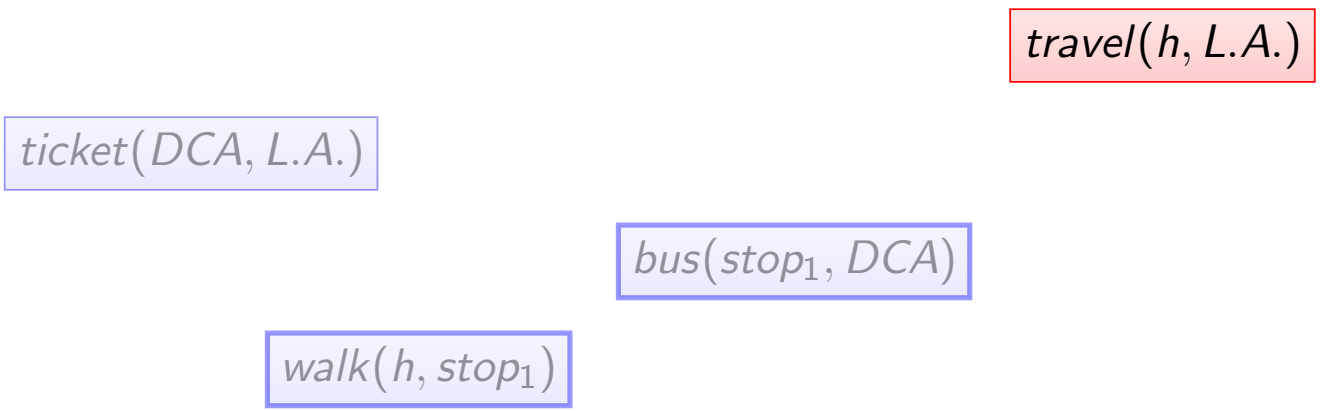
Task Insertion

- An alternate set of semantics, HTN Planning with Task Insertion (TIHTN Planning) allows the insertion of tasks without a method.



- Developed by Kambhampati (1998) and Biundo (2002)
- Used as a model for replanning and search with partial HTN knowledge

Replanning with TIHTNs



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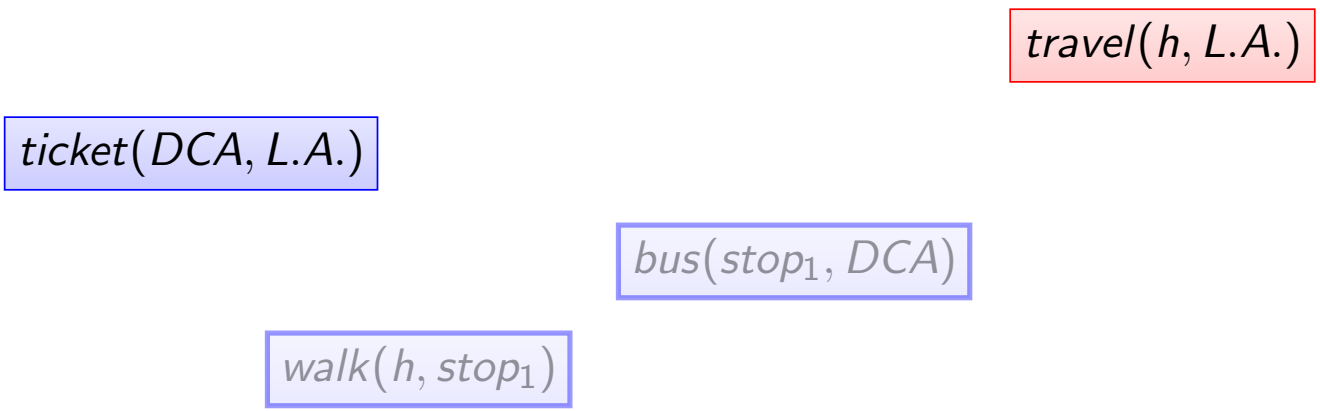

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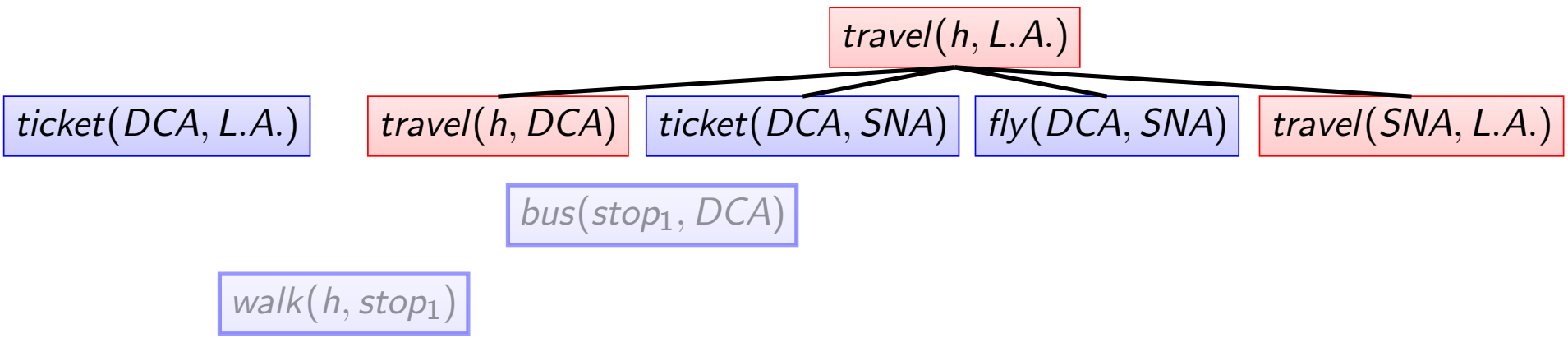

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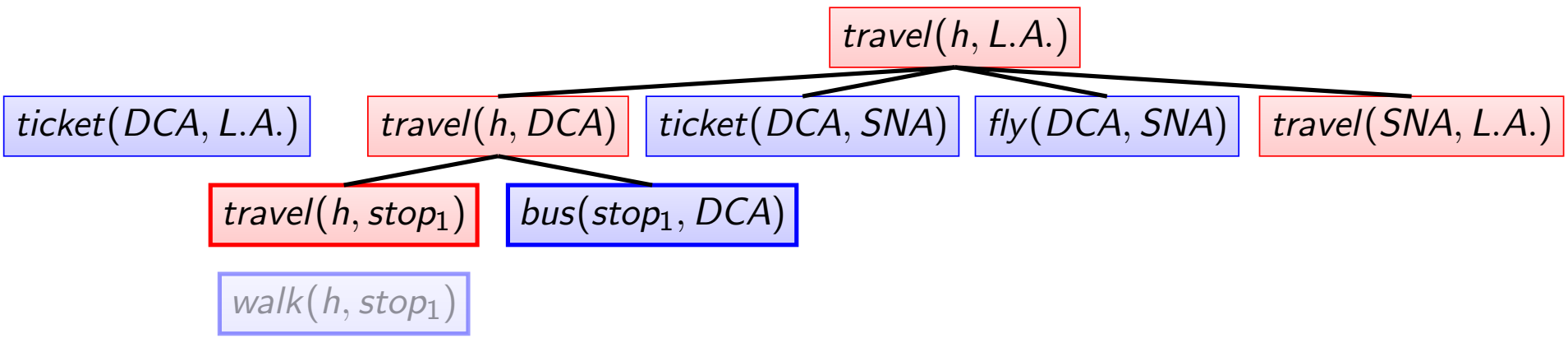

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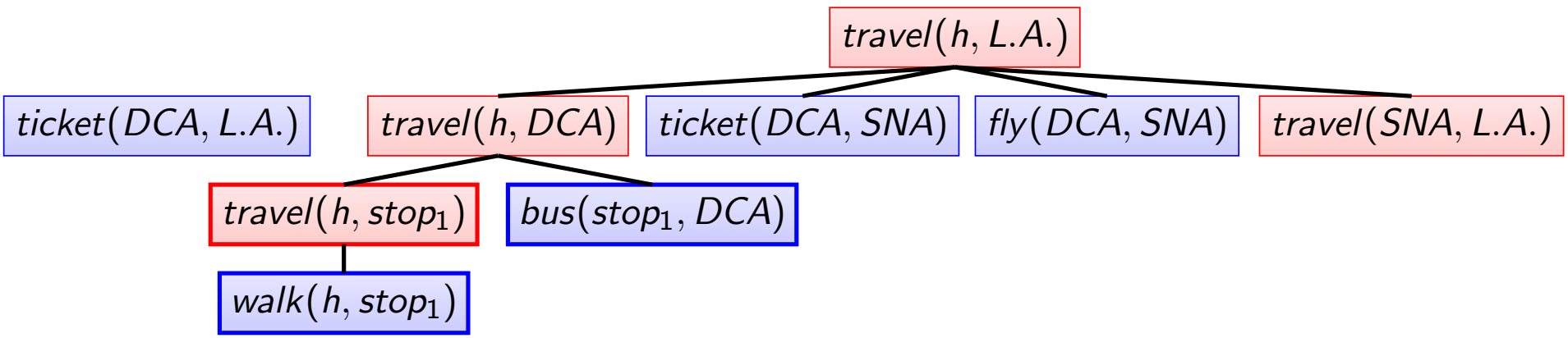

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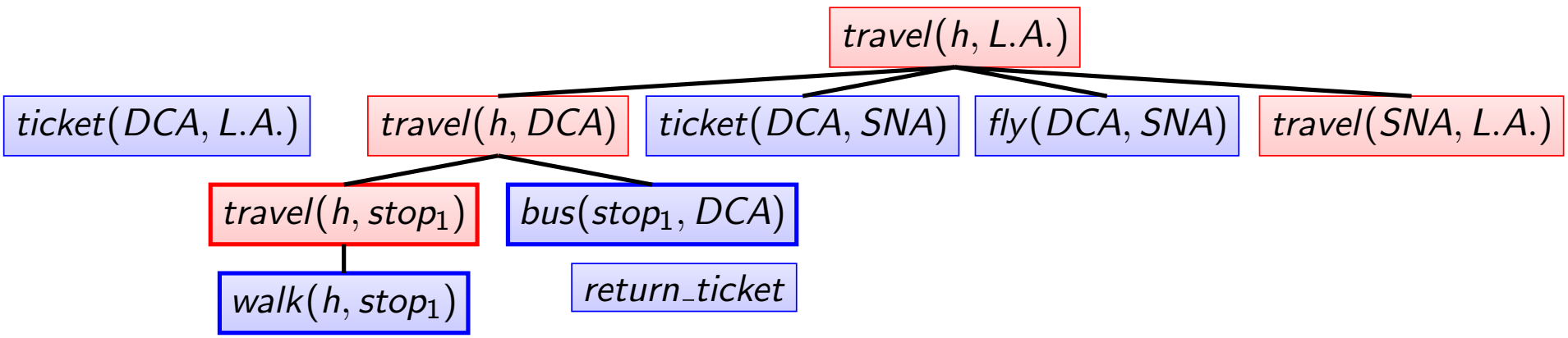

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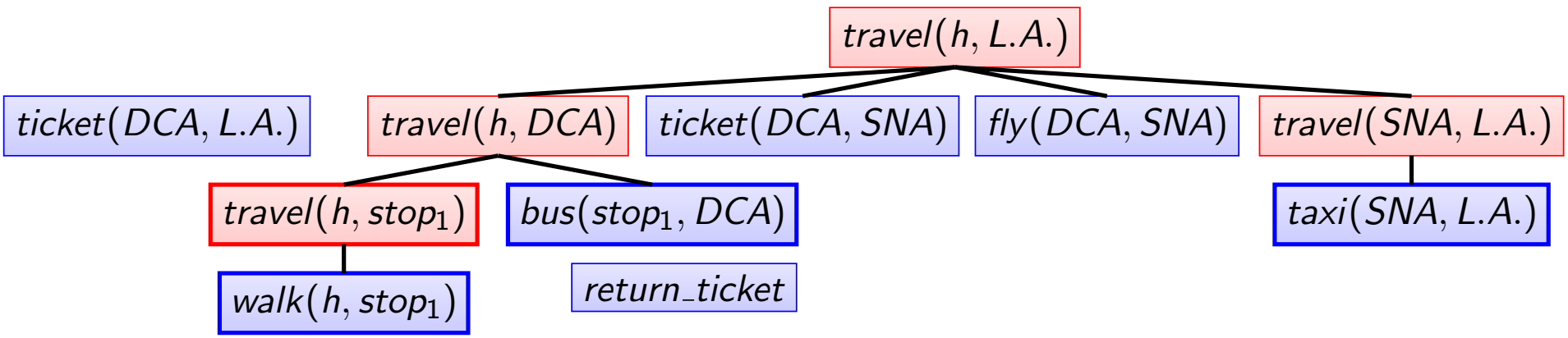

Why do we study complexity?

- TIHTN is decidable (Geier & Bercher, 2011)
  - Very little research on algorithms for TIHTN planning
  - No theoretical comparison, none guaranteed to terminate
- Decision procedures are important for model checking, non-deterministic planning, translation-based planning
- Method structures impact decidability and complexity:
  - Whether the method's tasks are totally-ordered
  - Where in the method recursion may occur
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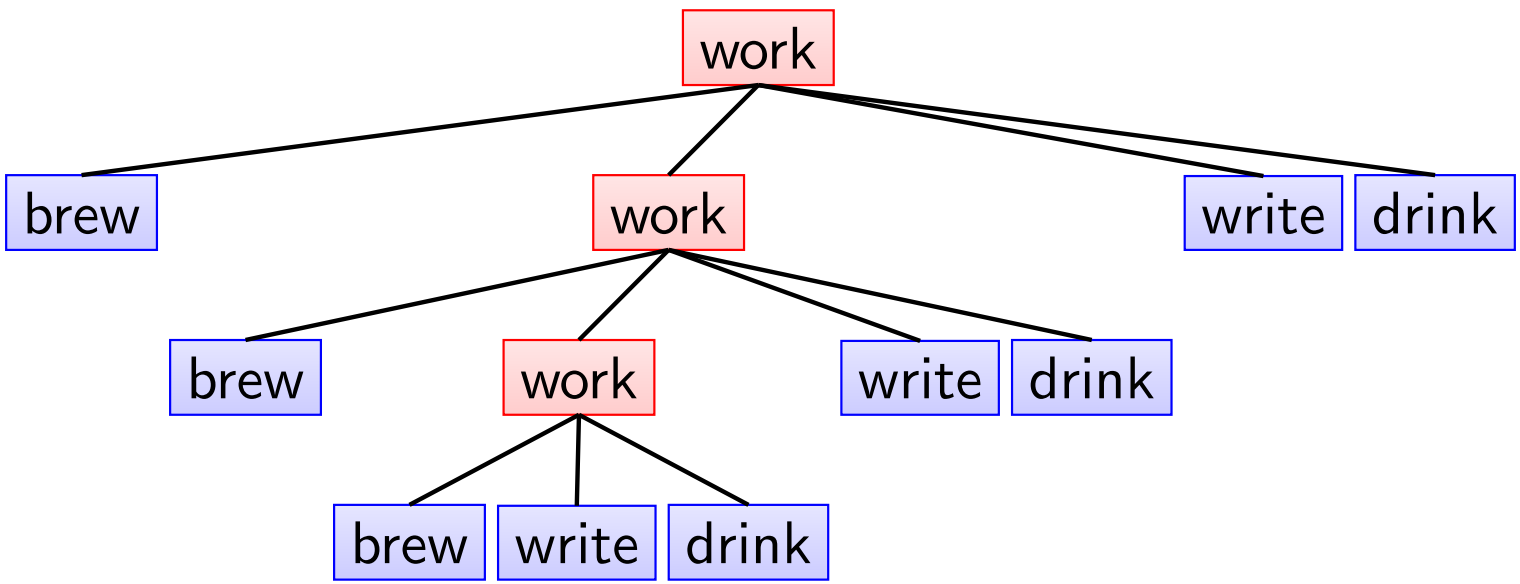

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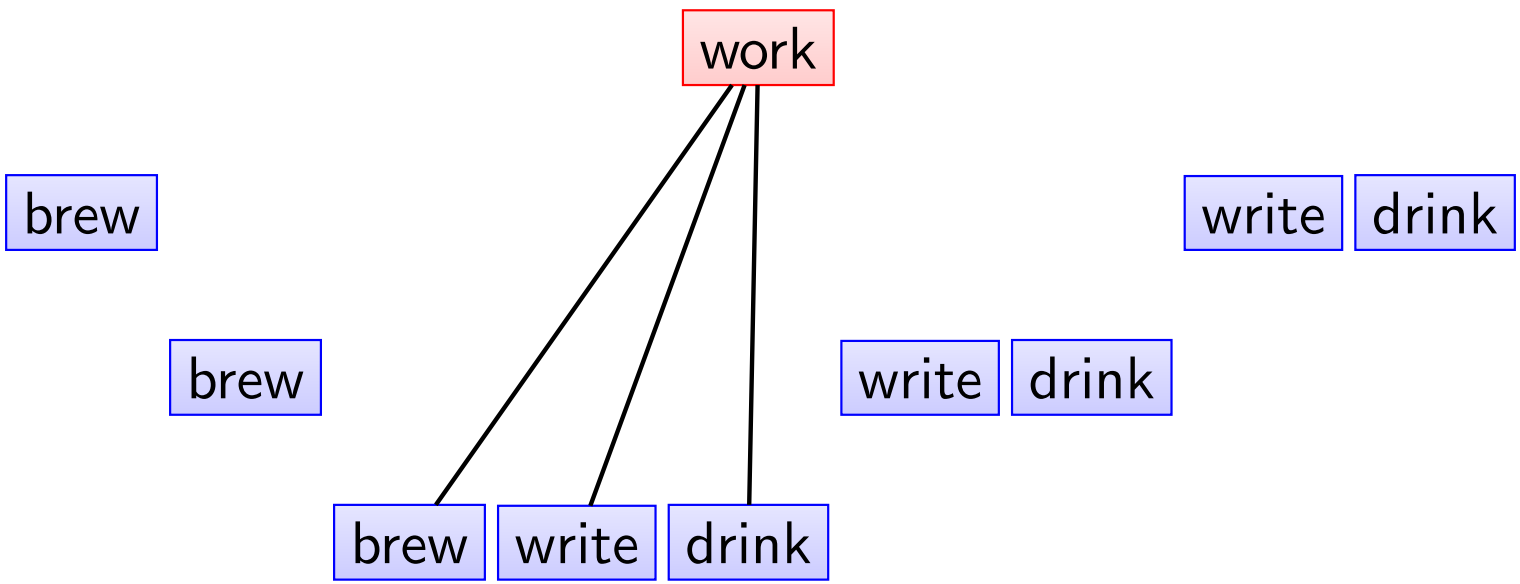
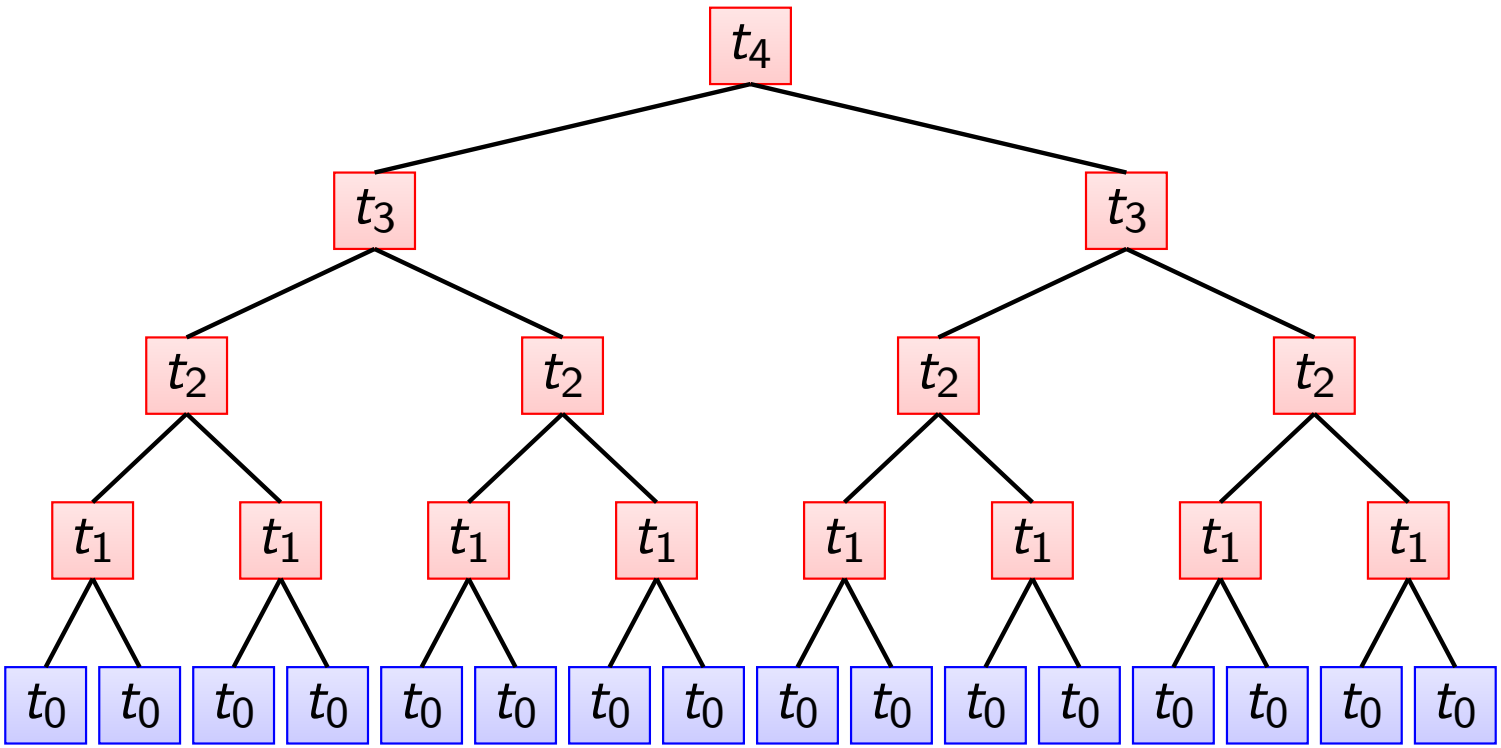


Planning with finite trees



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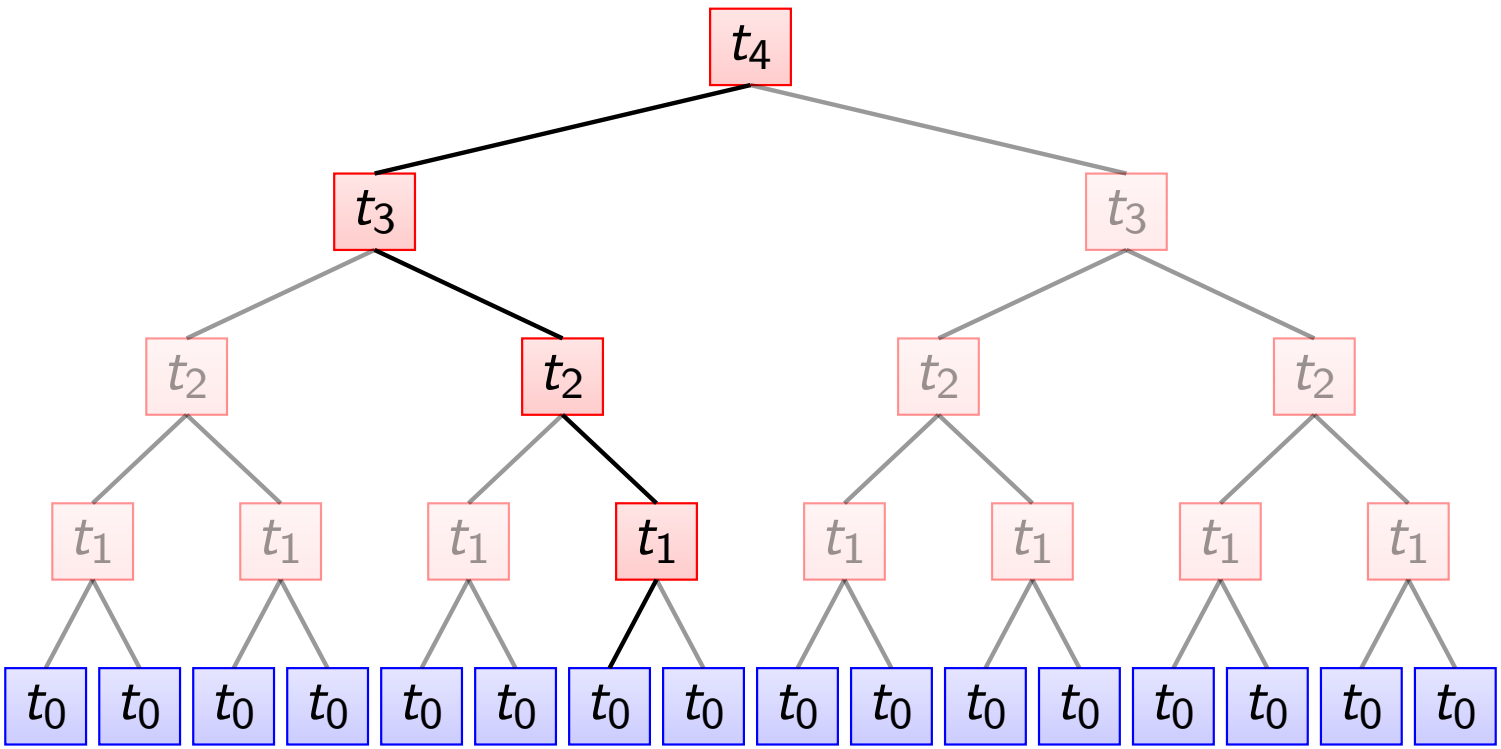
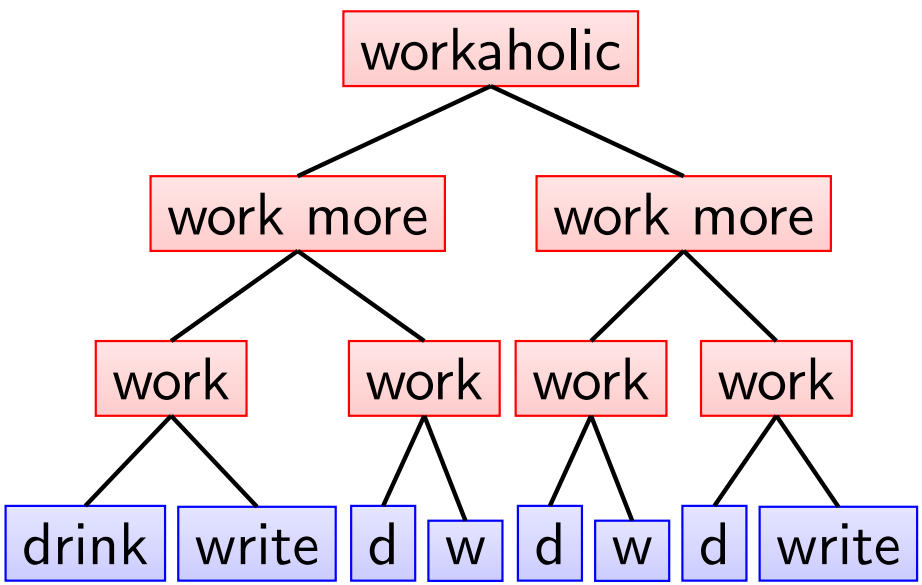


Acyclic HTN planning

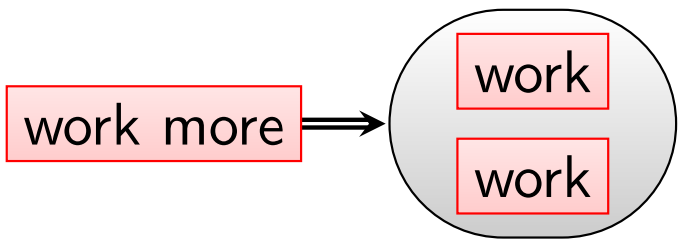
Acyclic HTNs:

- No recursion allowed
- Useful for program configuration (Soltani, 2012)



Method (totally-ordered):

Method (partially-ordered):



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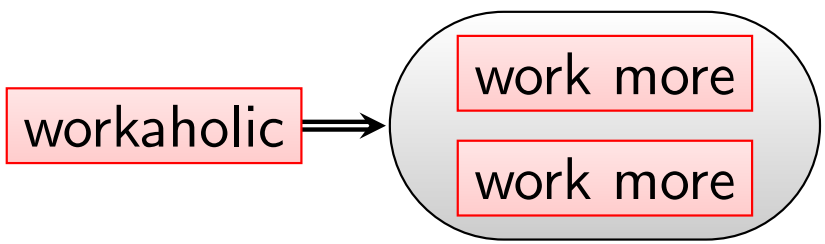


Acyclic HTN planning, with and without task insertion

Acyclic HTNs:

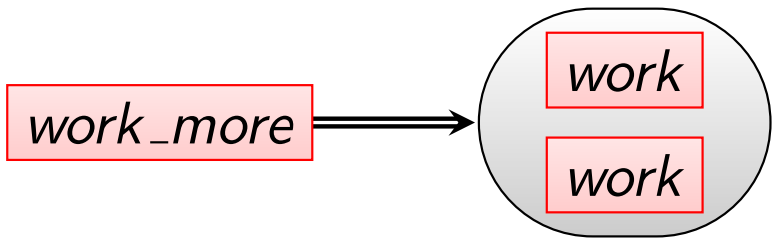
- No recursion allowed
- NEXPTIME-complete
- Every decomposition in NEXPTIME proof has same number of tasks

With insertion:

- Use counting technique to limit insertions
- TIHTN planning is NEXPTIME-complete

Method (totally-ordered):

Method (partially-ordered):



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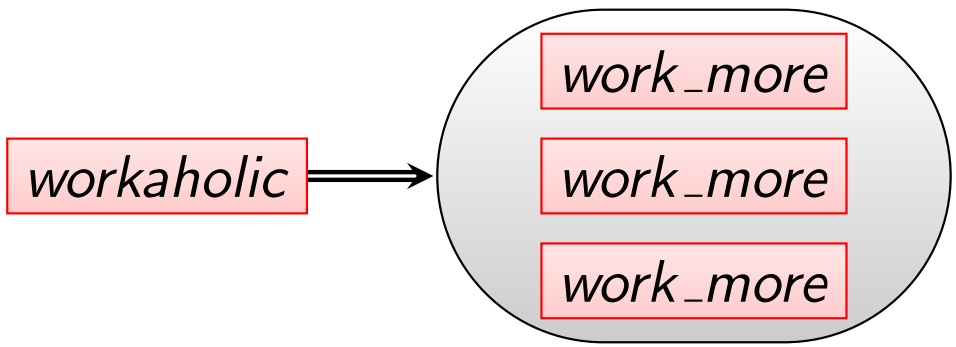
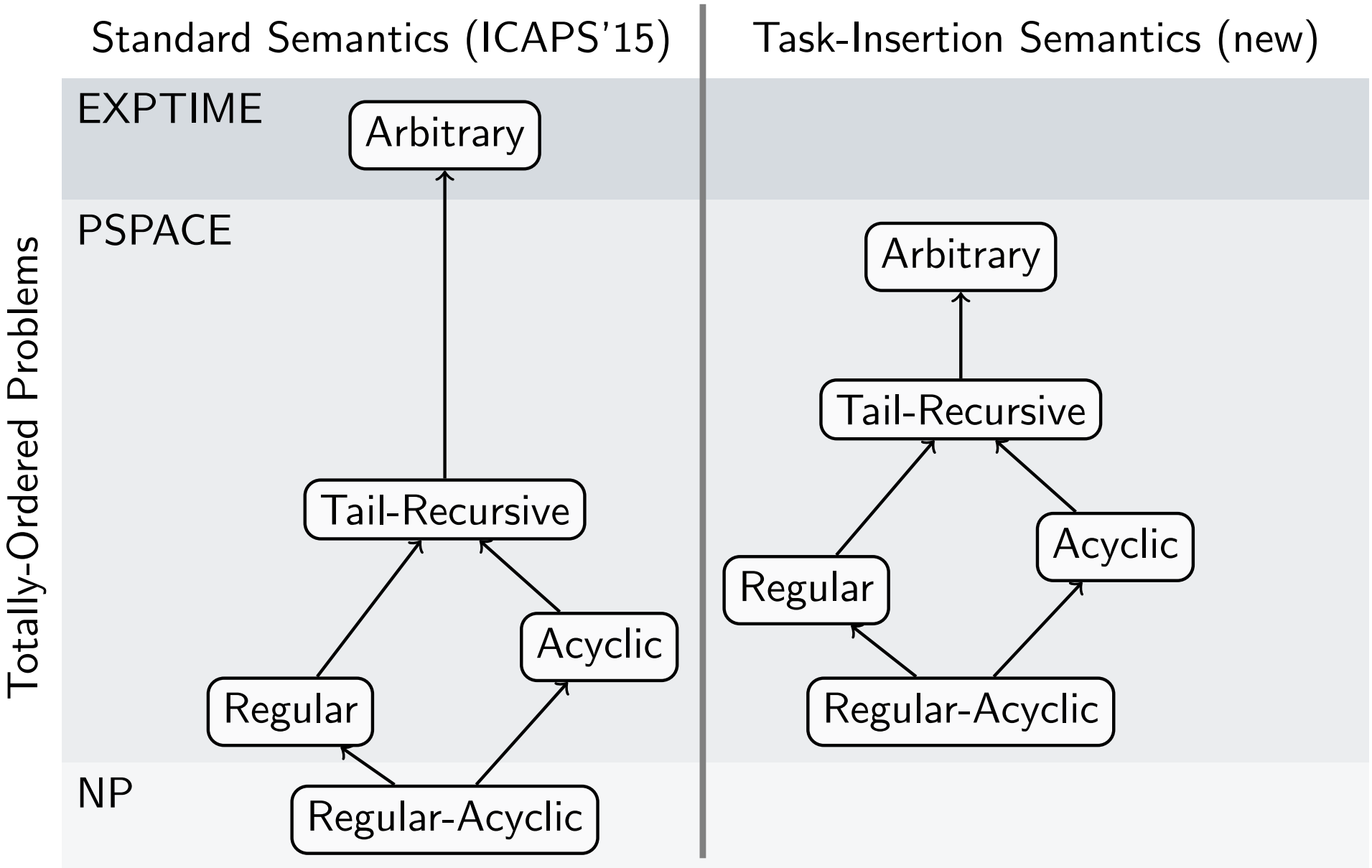


Totally-Ordered Propositional HTN Complexity



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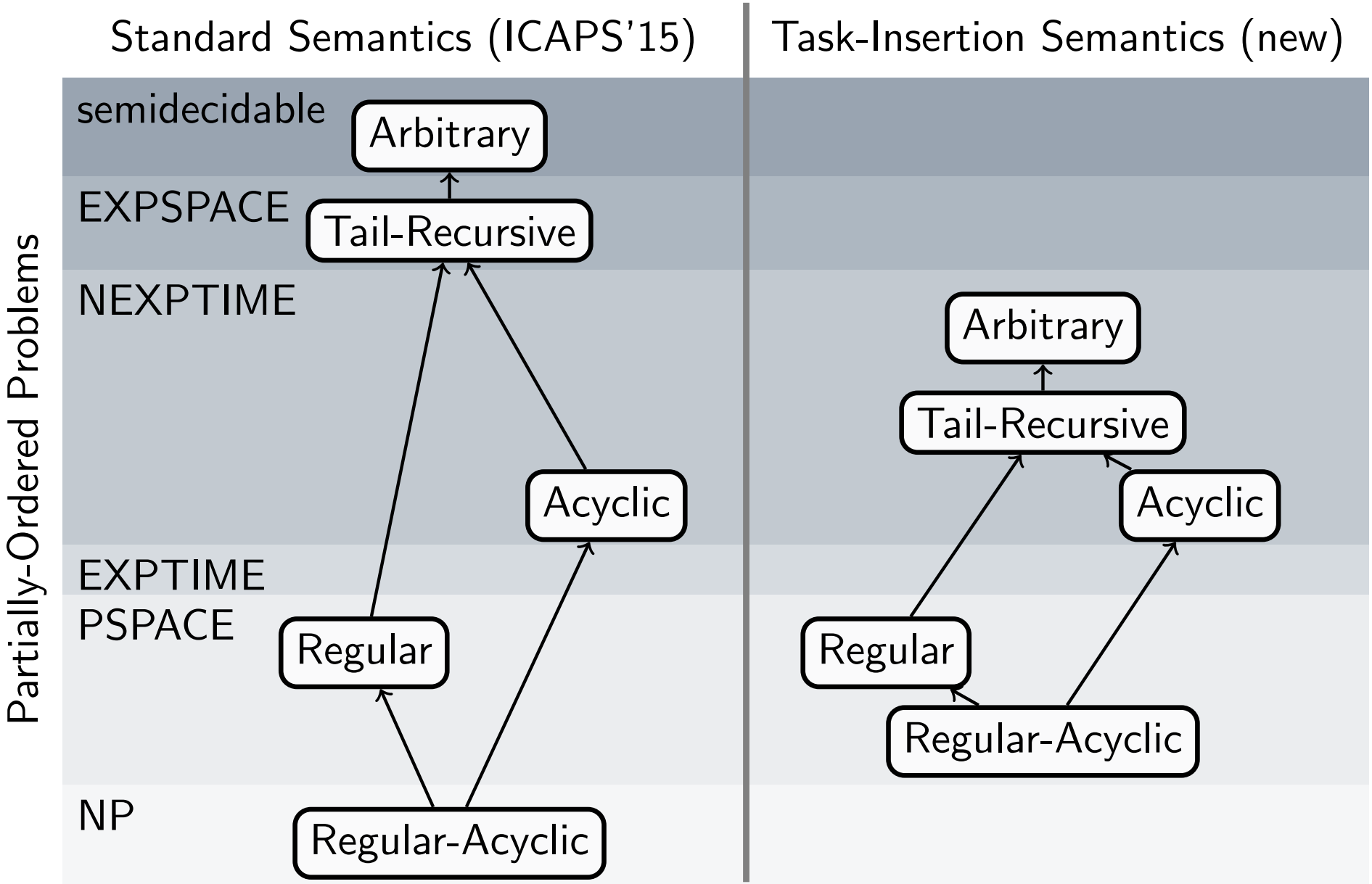
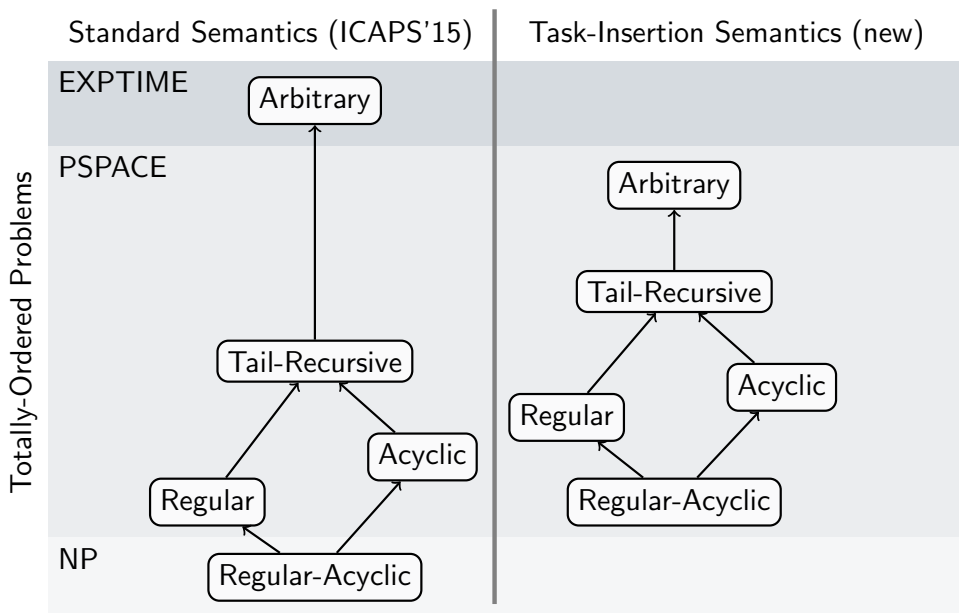
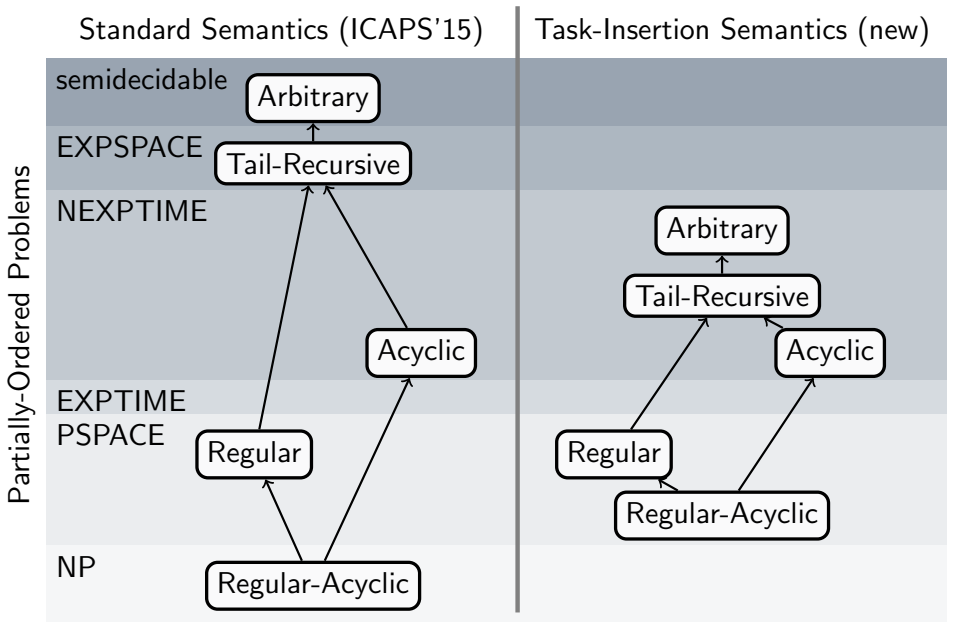


Contributions

Provided:

- New complexity bounds for all combinations of:
  - Propositional or non-propositional methods and actions
  - Partially or totally-ordered methods
  - General or regular method structures
- Theoretically-efficient algorithm for TIHTN planning





Implications

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For search people: We state-space search algorithm for TIHTN planning

- A^* needs duplicate detection
  - DAG isomorphism is GI-complete
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- Acyclic progression is just one blocking technique (may be others)

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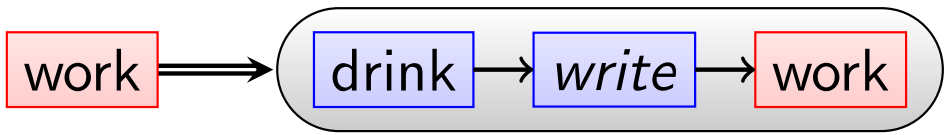
For domain-independent heuristicists:

- Very few domain-independent TIHTN heuristics
- Delete-free TIHTN planning is poly-time decidable, but?

Method structures: Regular & Tail-Recursive

- Only allowed to recurse through last task
- Only last task in regular HTNs can be non-primitive
- Tail-recursion generalizes acyclic HTNs

Method (totally-ordered regular):



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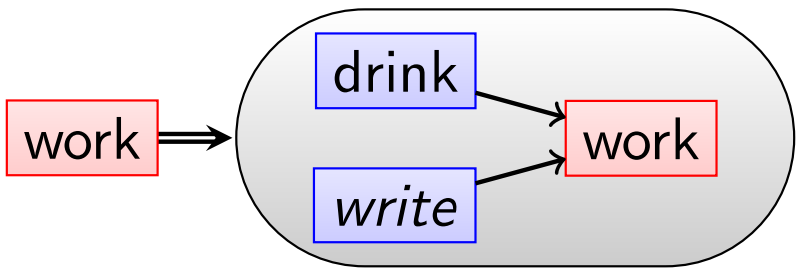
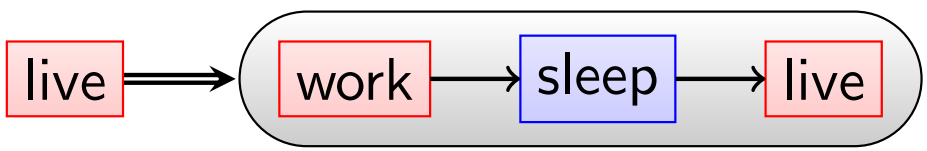


Method (totally-ordered tail-recursive):



Method structures: Arbitrary

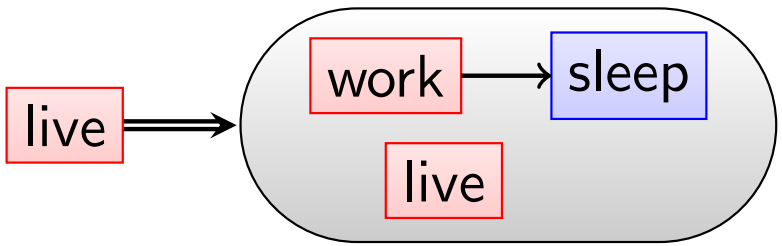
Partially-ordered arbitrary problems:

- Can express intersection of CFGs
- Semi-decidable

Totally-ordered arbitrary problems:

- Sometimes used for program representation
  - Web services (Sirin, 2004)
  - Java security (Kuter, 2015)
- Relatively easy to encode 2-player game tree search (chess, checkers)

Method (partially-ordered):



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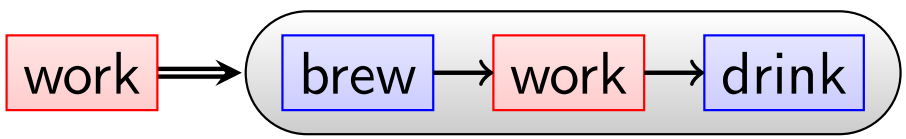

Results on Acyclic Progression

- Task networks are size-bounded under acyclic progression
- Size bounds if n is the number of task names and m is the size of the largest method
  - $m \cdot n$ for totally-ordered problems
  - m^n for partially-ordered problems