Improving Coordinated SMT-Based System Synthesis by Utilizing Domain-specific Heuristics

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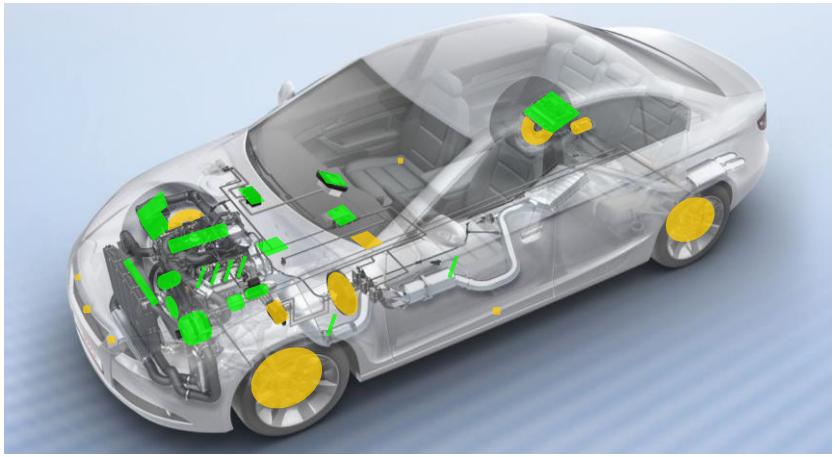
Automotive Domain: Embedded Systems



- Powertrain systems
- Safety systems
  - Electronic Stability Control (ESC)
  - Antilock Bracking System (ABS)

Electronic control unit embedded in physical context

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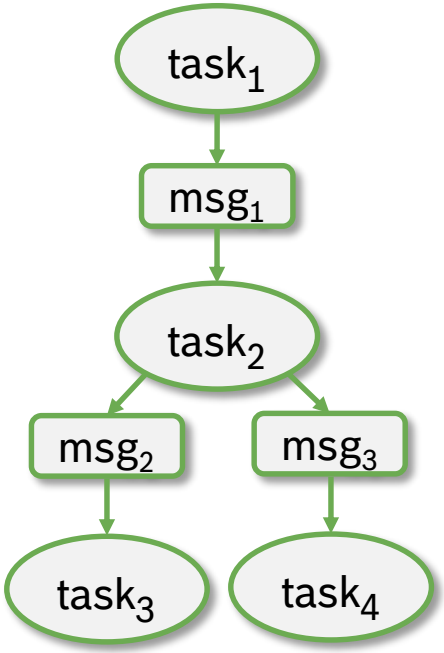
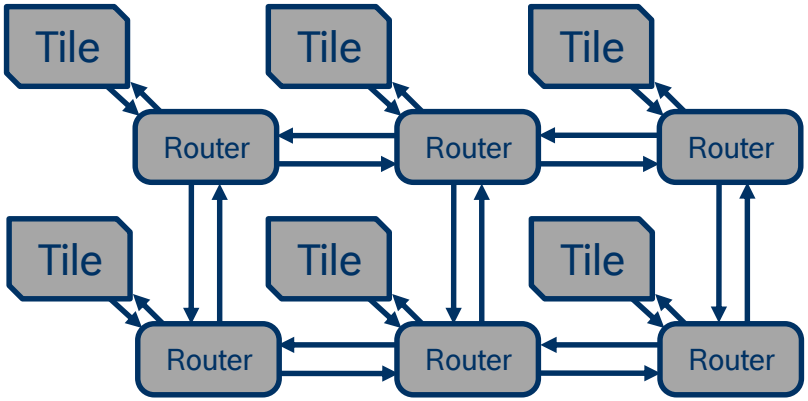
System Synthesis =

Software (SW)



Parallel Hardware (HW)



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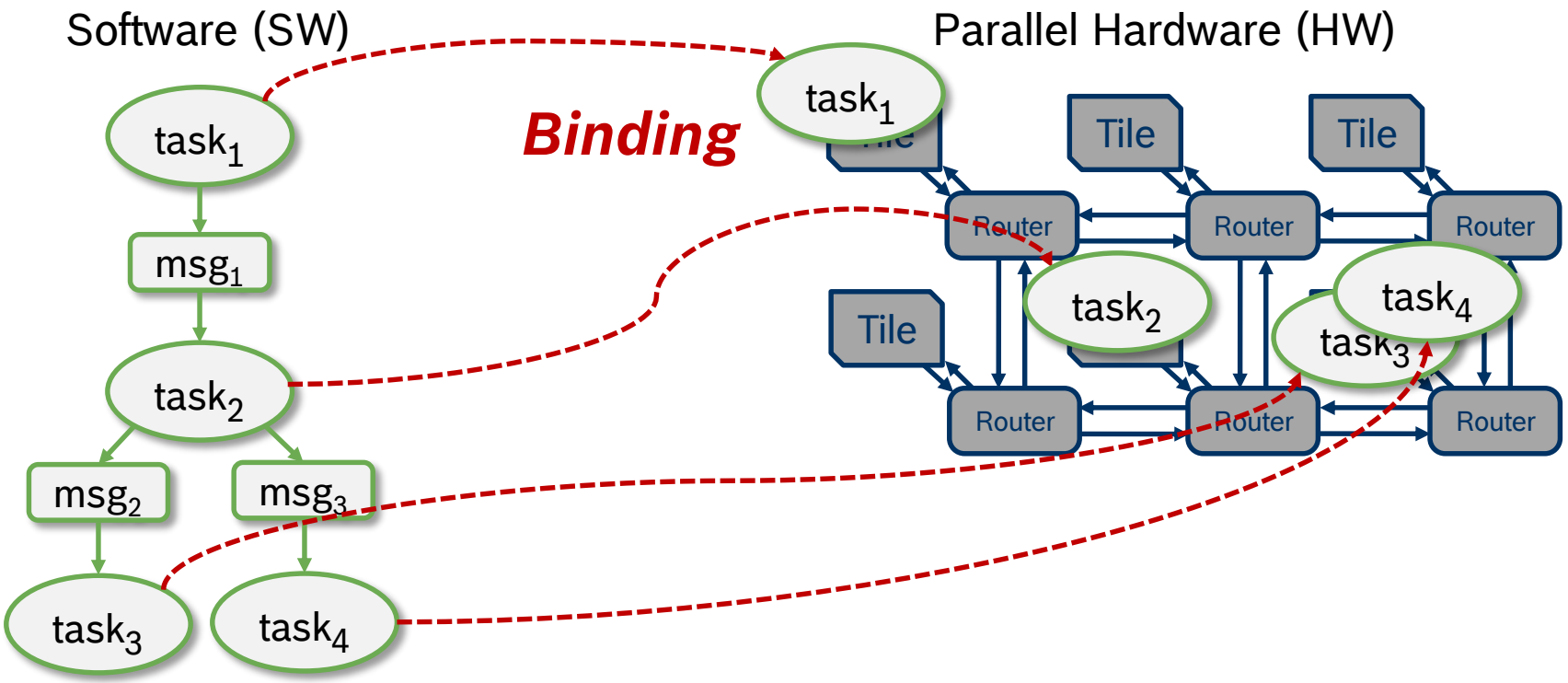
System Synthesis =



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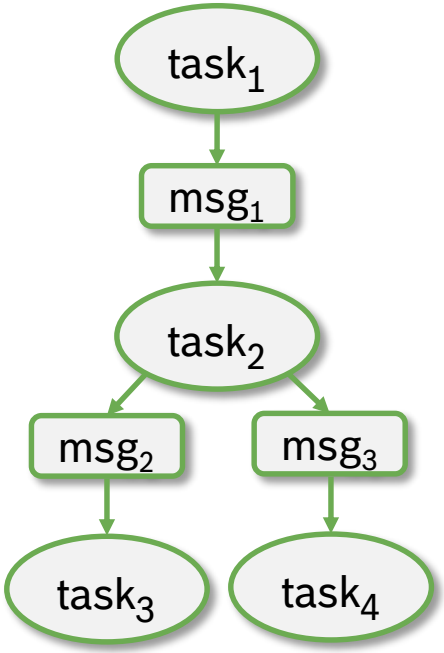
System Synthesis =

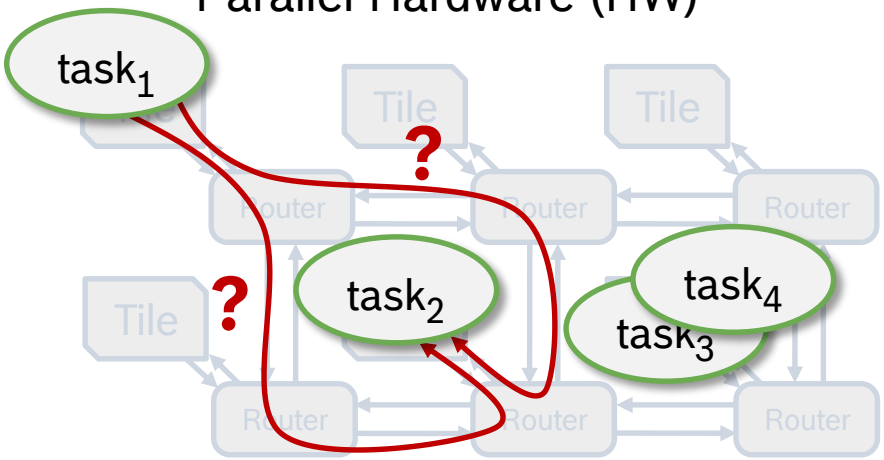
Software (SW)



Binding

+ Routing

Parallel Hardware (HW)



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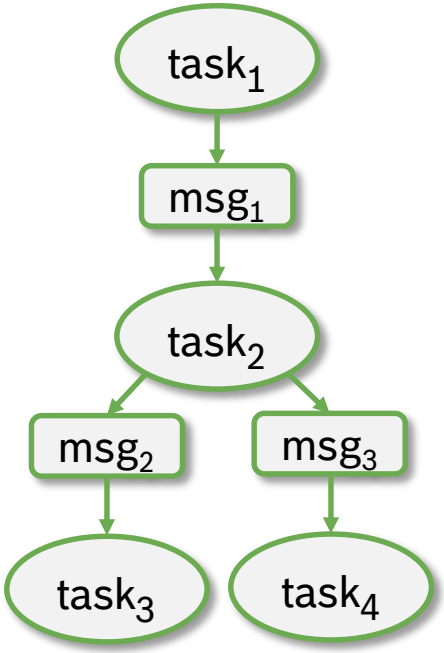

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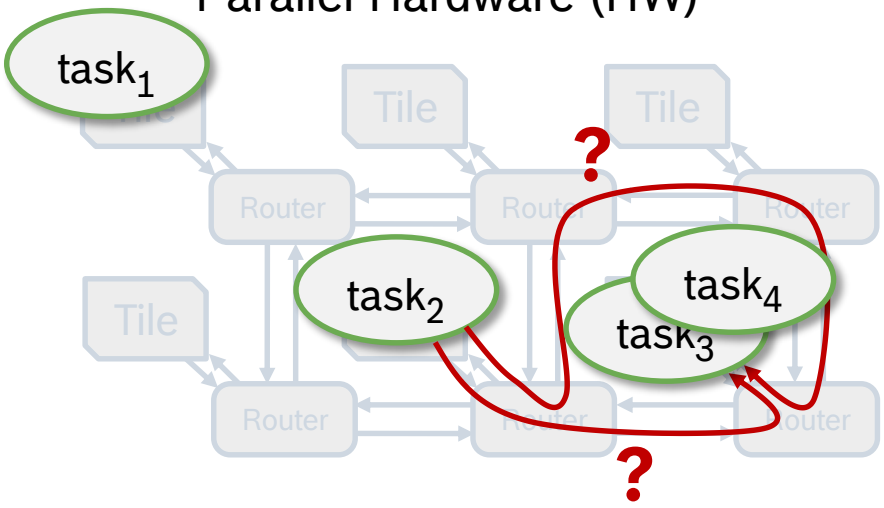

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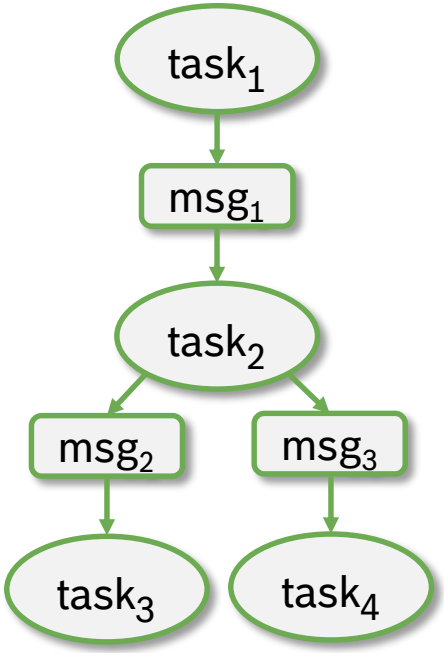

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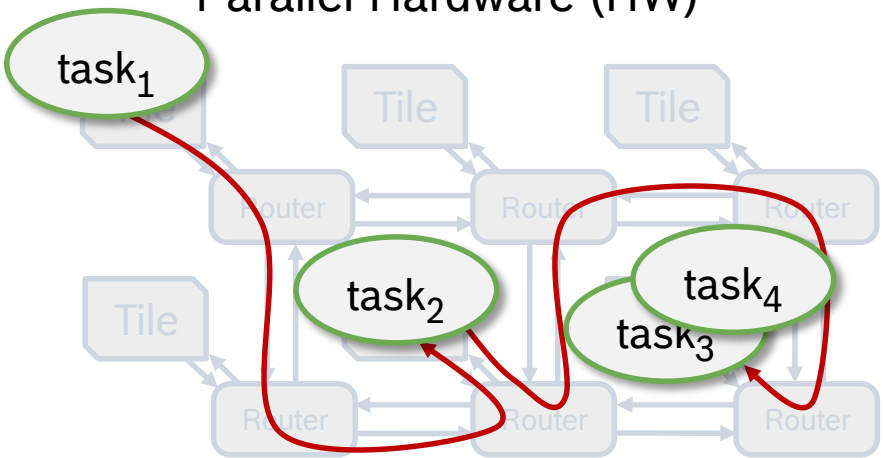

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System Synthesis =

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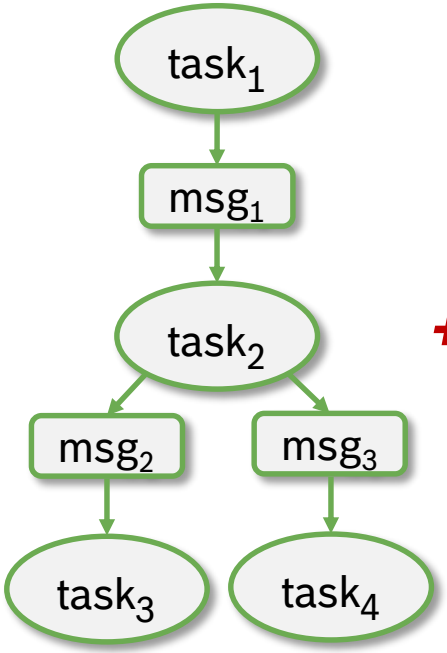
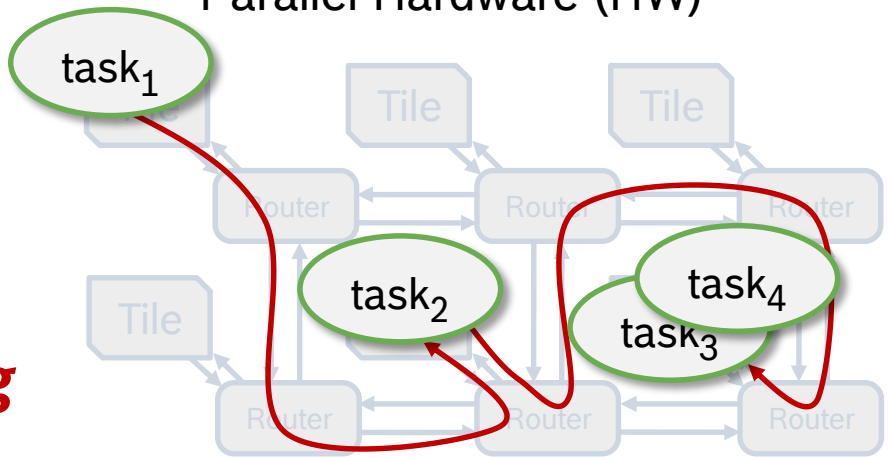


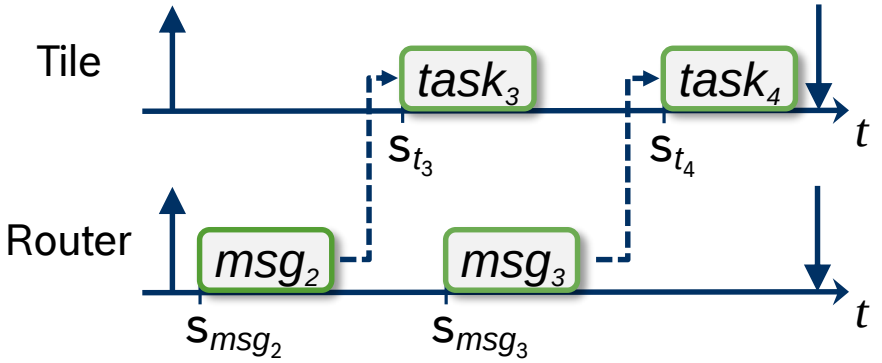
Binding

+ Routing

+ Scheduling

Parallel Hardware (HW)





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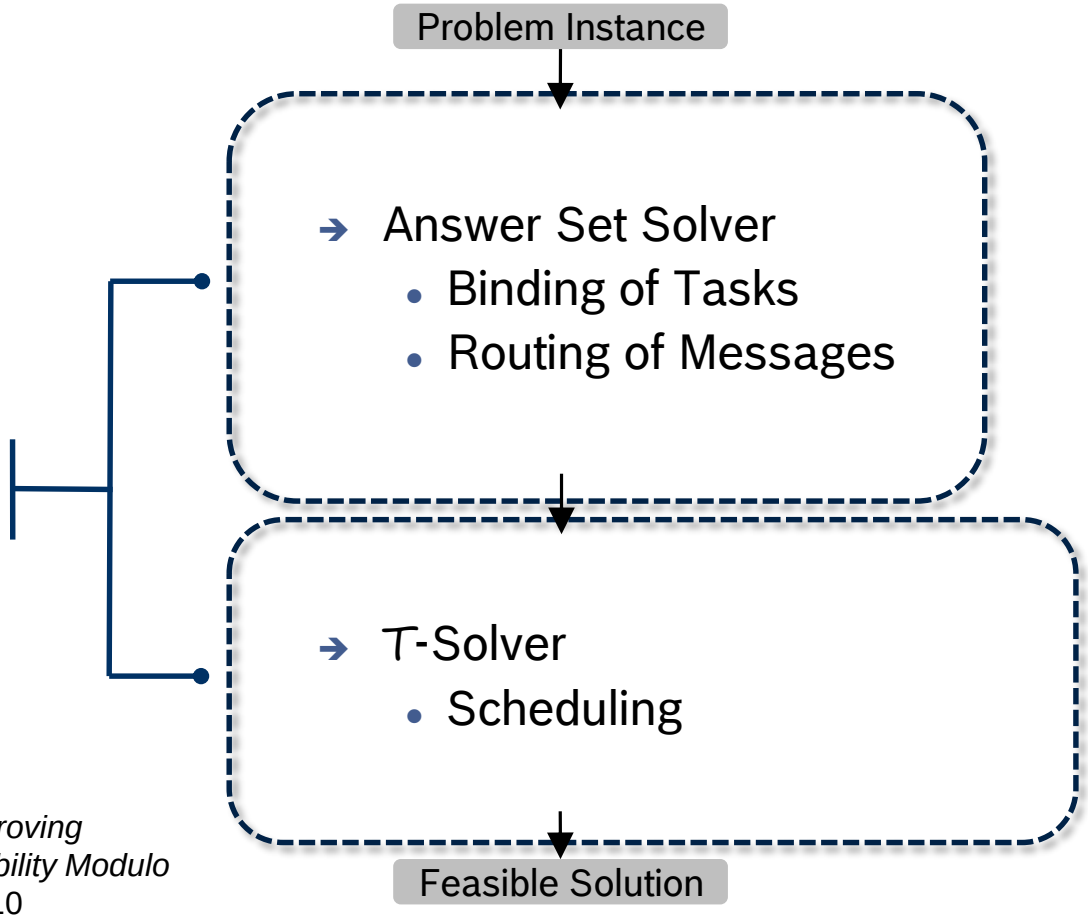
SMT-Based System Synthesis

Split work[1] among answer set solver and theory solver ($\mathcal{T}$-solver)



[1] Reimann, Glaß, Haubelt, Eberl, Teich: *Improving Platform-Based System Synthesis by Satisfiability Modulo Theories Solving,* Proc. of CODES+ISSS, 2010

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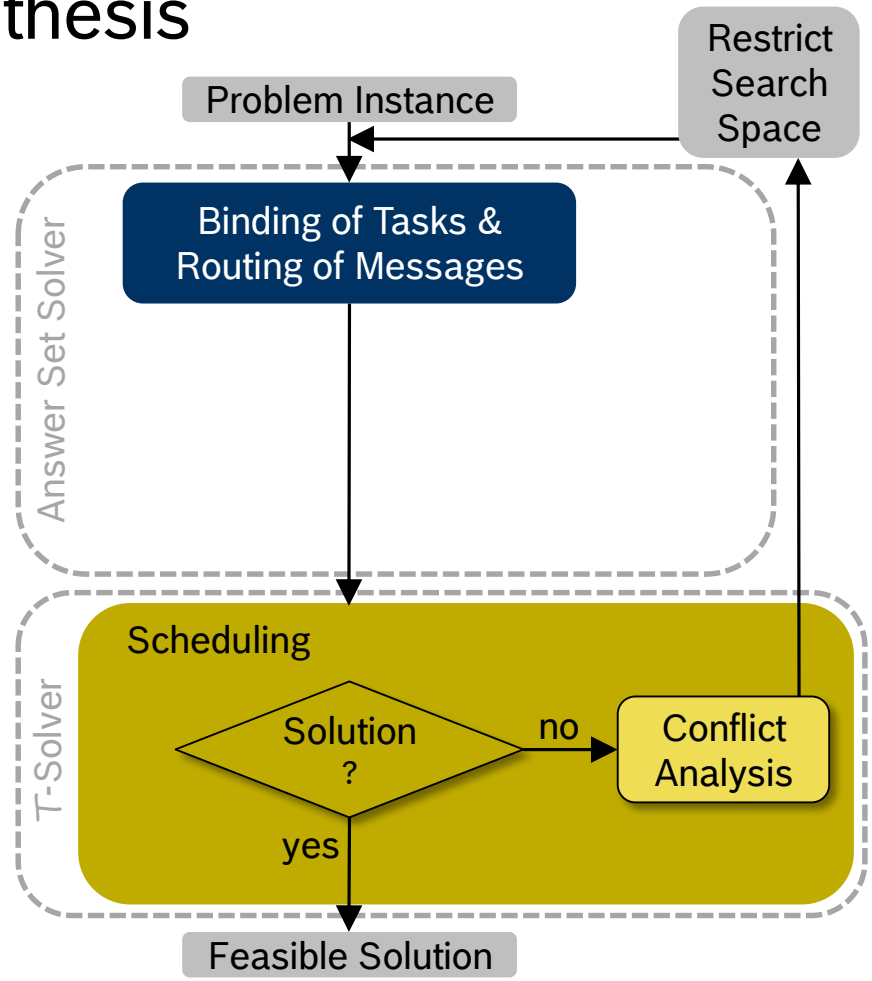
SMT-Based System Synthesis

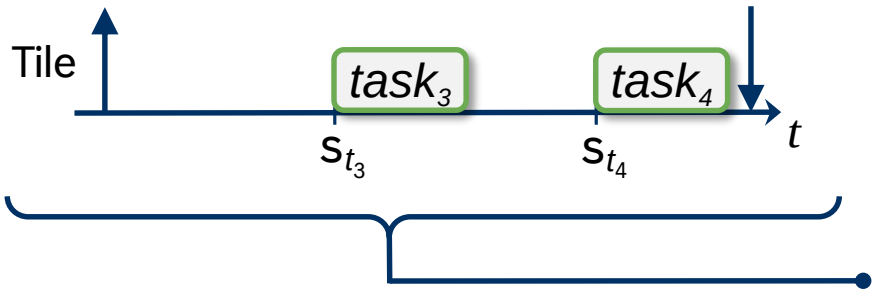


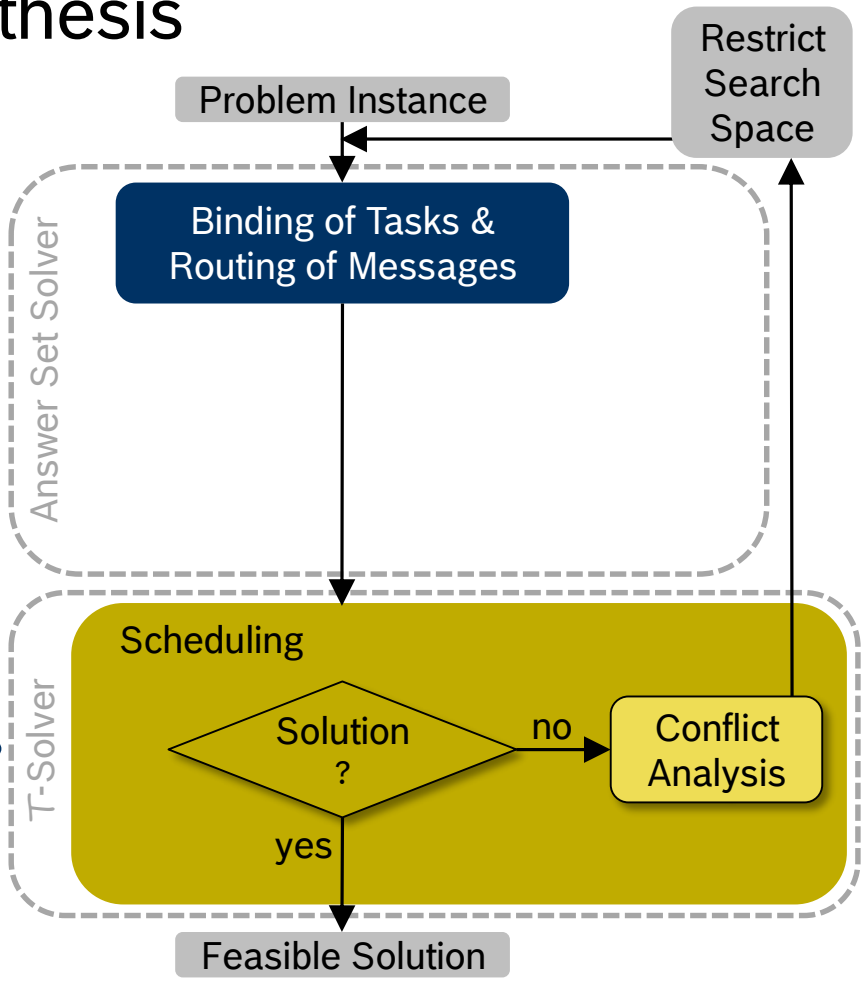
SMT-Based System Synthesis

- Quantifier-free integer difference logic (QF_IDL)

$$s_{t_3} - s_{t_4} \leq k \qquad (1)$$

$$s_{t_3}, s_{t_4} \in \mathbb{N} \quad k \in \mathbb{Z}$$





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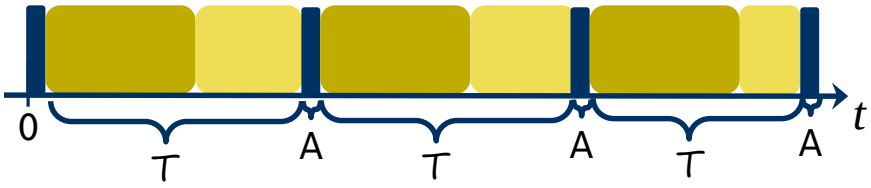
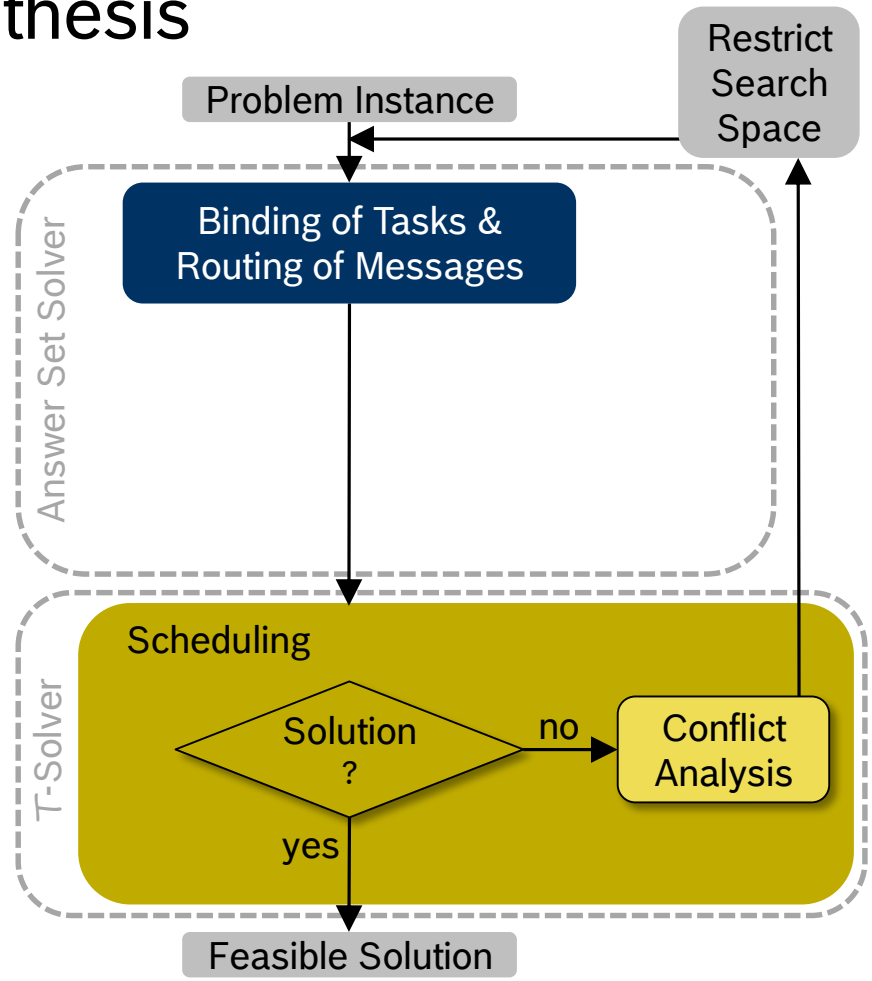
SMT-Based System Synthesis

- Runtime Characteristics





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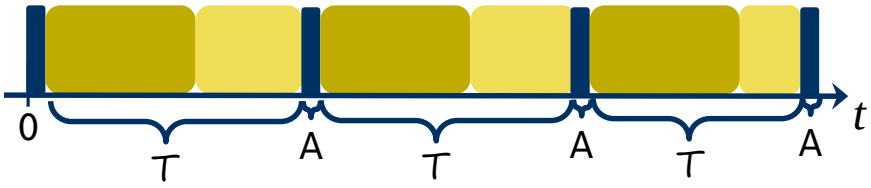
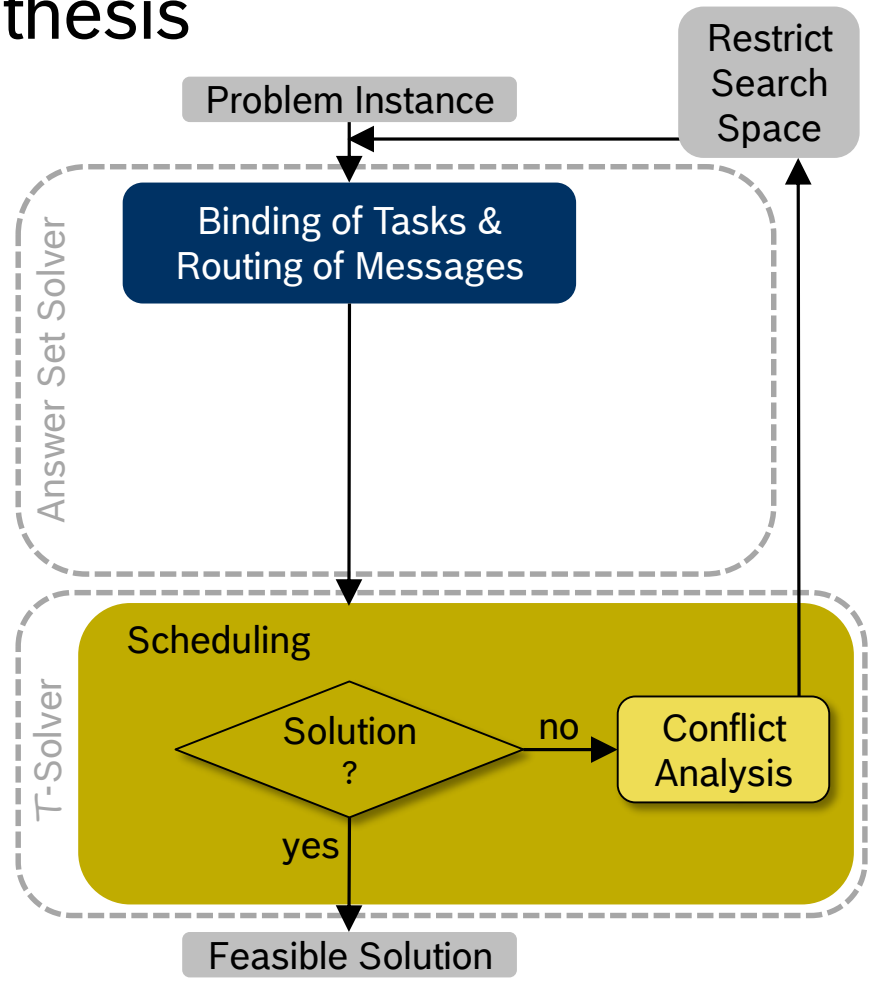


- **Coordination between solvers**[2]
  - Expect problems that can be decided within a reasonable amount of time in the $\mathcal{T}$-Solver



[2] Biewer, Andres, Gladigau, Schaub, Haubelt: *A Symbolic System Synthesis Approach for Hard Real-Time Systems Based on Coordinated SMT-Solving, Proc. of DATE,* 2015

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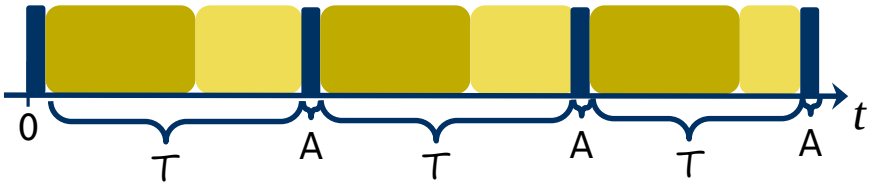
Improved SMT-Based System Synthesis

- Runtime Characteristics



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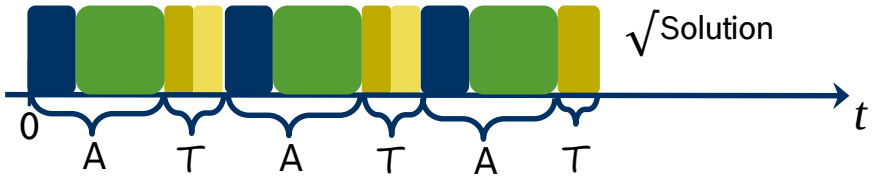

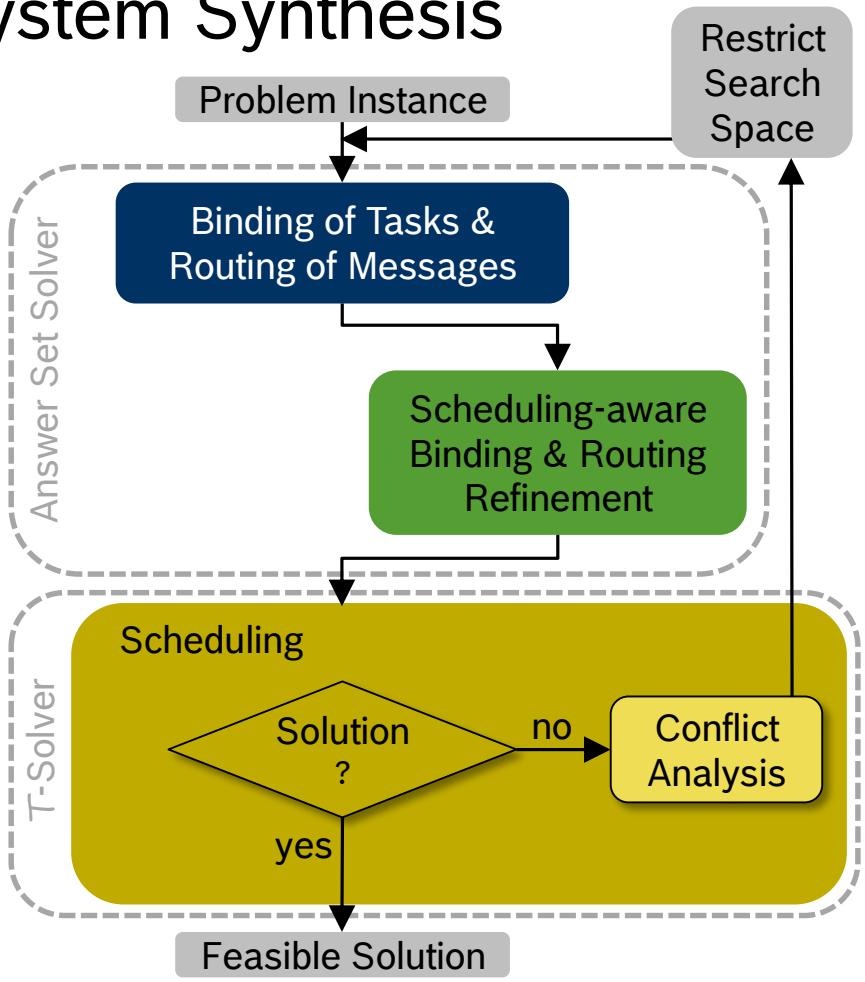

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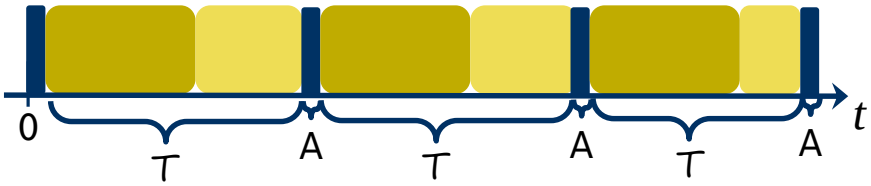

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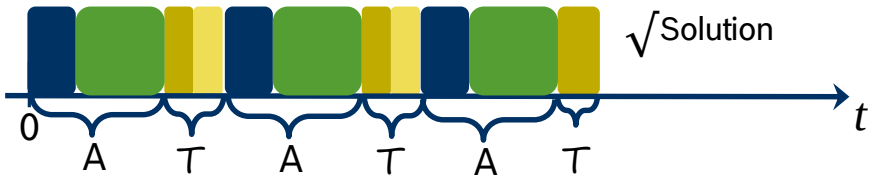

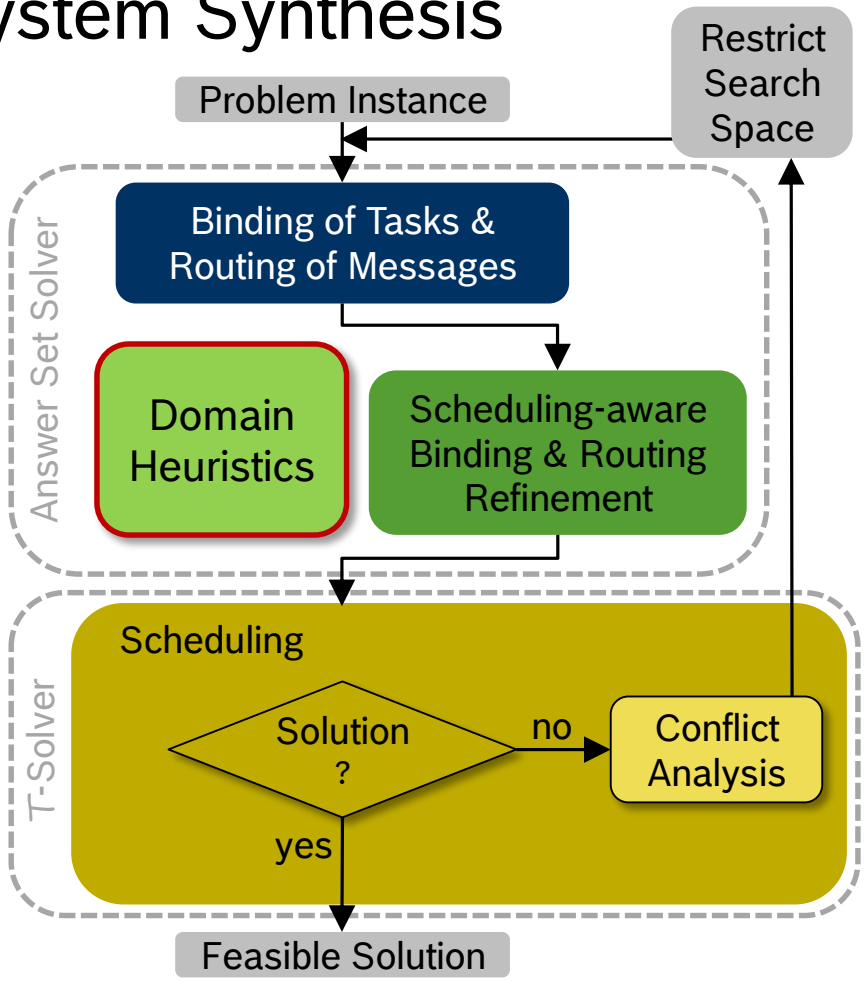

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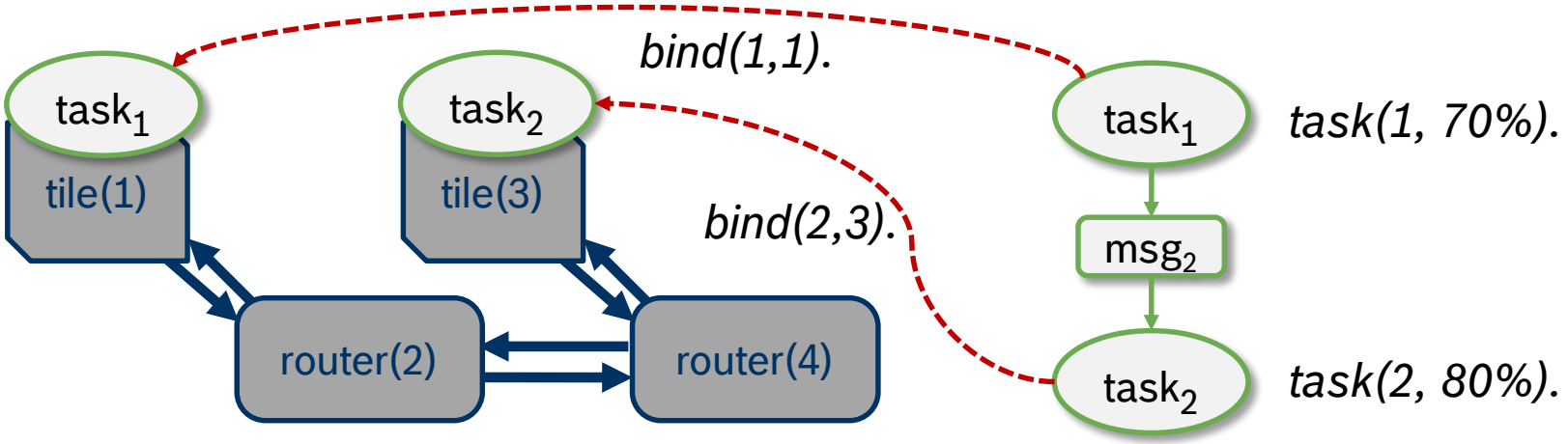
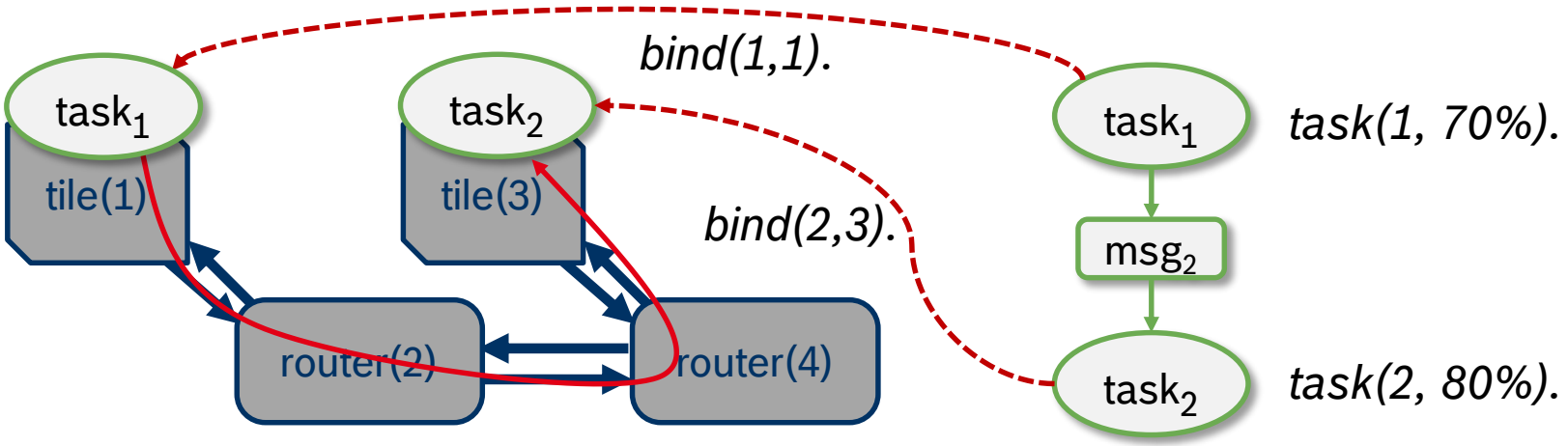
ASP Encoding (excerpt)

- Bind each computational task to one tile
  - 1 { *bind(T,R)* : *tile(R)* } 1 :- *task(T,U).*
- Ensure utilization limit of tiles (100%)



ASP Encoding (excerpt)

- Bind each computational task to one tile
  - 1 { *bind(T,R)* : *tile(R)* } 1 :- *task(T,U).*
- Ensure utilization limit of tiles (100%)
- Routing[3]
  - 1 { *reached(M,R,S)* : *edge(R,S)* } 1 :- ...



reached(2,1,2). reached(2,2,4). reached(2,4,3).

[3] Andres et al.: *Symbolic System Synthesis Using Answer Set Programming*, LPNMR, 2013

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Our Heuristics

- Domain-specific heuristics in clasp[4]
  - Modifiers sign, level, init, factor in dedicated atoms _heuristic
- Tested over 60 different heuristics (combinations)

- **H1 – bindings first, then routing**
  - _heuristic(*bind(T,R)*, level, 2) :- …
  - _heuristic(*reached(M,R,S)*, level, 1) :- …
- **H2 – discourage routing**
  - _heuristic(*reached(M,R,S)*, sign, −1) :- …
- **H3 – binding sender & receiver together**
  - _heuristic(*bind(T*,R)*, sign, 1)
    :- … *bind(T,R), send(T,M), receive(T*,M)* …

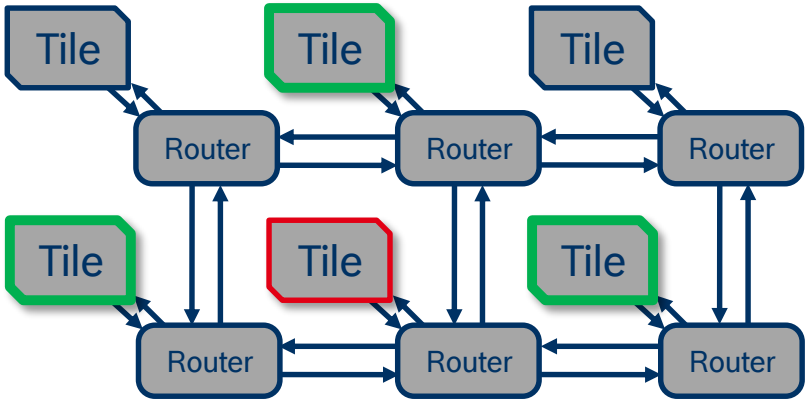
[4] Gebser, Kaufmann, Otero, Romero, Schaub, Wanko:
Domain-Specific Heuristics in Answer Set Programming, Proc. of AAAI, 2013

Our Heuristics (cont'd)

- **H4 – Clustering computational tasks**
  - _heuristic(*bind(T,R)*, true, *A+2*)
    :– … *bind(T*,R)*, *send(T*,M)*, *receive(T,M)*, *belongs(A,T)* …

Our Heuristics (cont'd)

- **H4 – Clustering computational tasks**
  - _heuristic(*bind(T,R)*, true, *A+2*)
    :– … *bind(T*,R)*, *send(T*,M)*, *receive(T,M)*, *belongs(A,T)* …
  - _heuristic(*bind(T,R)*, true, *A+1*)
    :– … *bind(T*,R*)*, *send(T*,M)*, *receive(T,M)*, *belongs(A,T)*,
    neighbor(R*,R)…



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Experimental Setup

- Solvers
  - clasp (via gringo python module)
  - Yices[5] & Z3[6] to solve background theory
- Instances
  - 60 different system instances (3 synthesis runs each)
    - All platforms were composed of 25 tiles and 25 routers
- Time limits
  - 15 minutes timeout for a synthesis run
  - Scheduling-aware binding & routing refinement set to 1 second
    - Optimize load balancing and minimization of send messages

[5] Dutertre: *Yices 2.2*, Proc. of CAV, 2014
[6] de Moura, Bjørner: *Z3: An Efficient SMT Solver*, Proc. of TACAS, 2008

Experimental Results (excerpt)

Strategy / Heuristic	Completely solved instances [of 60]	Partially solved instances [of 60]	Successful synthesis [of 180 runs]	Average synthesis time (successful)
Reference	4	32	35%	241secs
Reference with structural heuristic*	34	8	62%	249secs

*Structural heuristic: set atoms in minimization statements to *false*

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Strategy / Heuristic	Completely solved instances [of 60]	Partially solved instances [of 60]	Successful synthesis [of 180 runs]	Average synthesis time (successful)
Reference	4	32	35%	241secs
Reference with structural heuristic*	34	8	62%	249secs
H1	12	30	44%	259secs
H1 + H2 + H3	14	38	59%	262secs
H4	34	25	79%	110secs

H1 – bindings first, then routing
H2 – discourage routing
H3 – binding sender & receiver together
H4 – Clustering computational tasks

*Structural heuristic: set atoms in minimization statements to *false*

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Conclusions

- Introduced synthesis problem from the domain of embedded systems
- Coordinated SMT-based system synthesis
  - Scheduling-aware binding and routing refinement in ASP solver
- Presentation of our four most effective domain-specific heuristics
- By utilizing domain-specific heuristics we were able to…
  - … more than double the number of successful synthesis runs.
  - … obtain at least one feasible synthesis out of three attempts (with the exception of one instance).
  - At the same time, the average synthesis time was reduced by 50%

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