A discrete optimisation approach to scheduling of an integrated modular avionic system

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1 Joint research project

2 Problem description

3 Solution strategy

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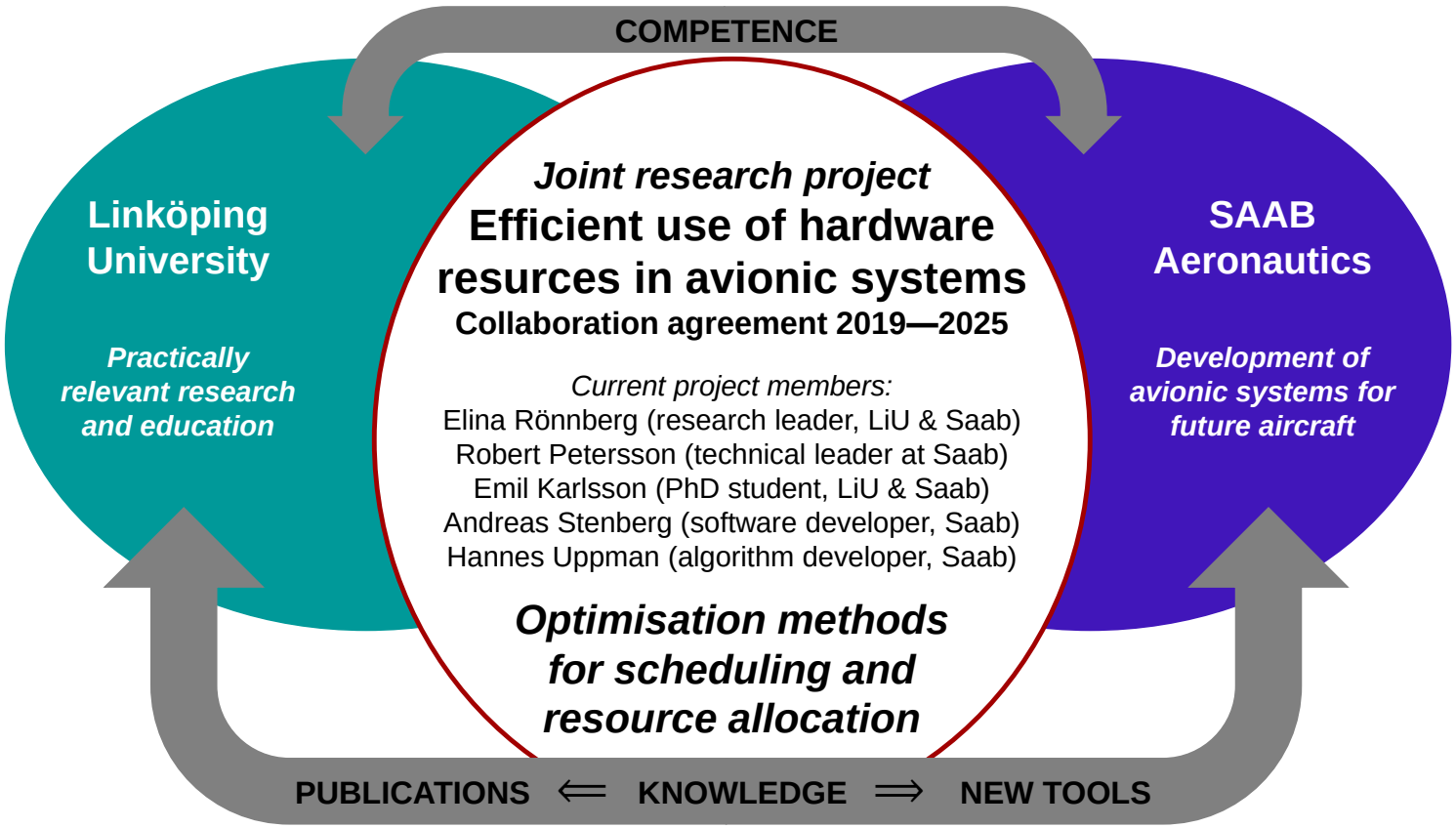
Joint research project between Saab and LiU



Today's topic

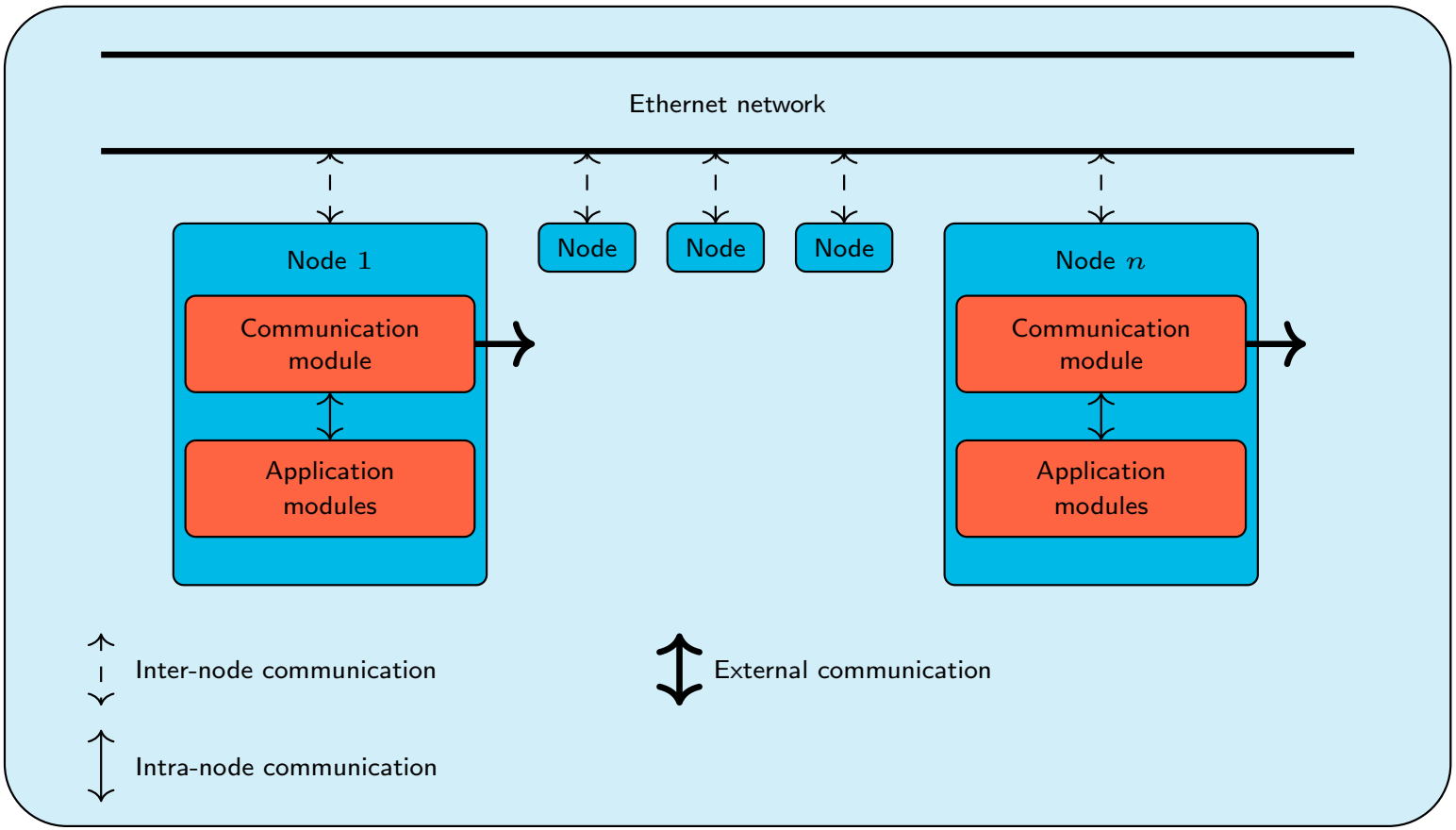
A pre-runtime scheduling problem

of interest for Saab in the development of future avionic systems

The integrated modular avionic system of interest

- An integrated modular avionic system where software applications can share hardware resources
- Software applications $\rightarrow$ processes $\rightarrow$ partitions $\rightarrow$ application modules
- Processes of mixed criticality on the same application modules thanks to a robust partitioning in line with ARINC 653
- Processes communicate via communication modules that are connected to a time-slotted Ethernet network

An illustration of the avionic system



Hierarchical scheduling of the system

- Software applications $\rightarrow$ processes $\rightarrow$ partitions $\rightarrow$ application modules

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- *Pre-runtime schedule of*
  - *partitions within the same application module*
  - *tasks on communication modules*
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Hierarchical scheduling of the system

- Software applications $\rightarrow$ processes $\rightarrow$ partitions $\rightarrow$ application modules
- *Pre-runtime schedule of*
  - *partitions within the same application module*
  - *tasks on communication modules*
  - *messages on a time-slotted Ethernet network*
- Dispatching according to the pre-runtime schedule
- Rate-monotonic scheduling of processes within the same partition

A pre-runtime avionic scheduling problem

We want to

- Assign start times to tasks on modules
- Assign messages to time-slots on the Ethernet network

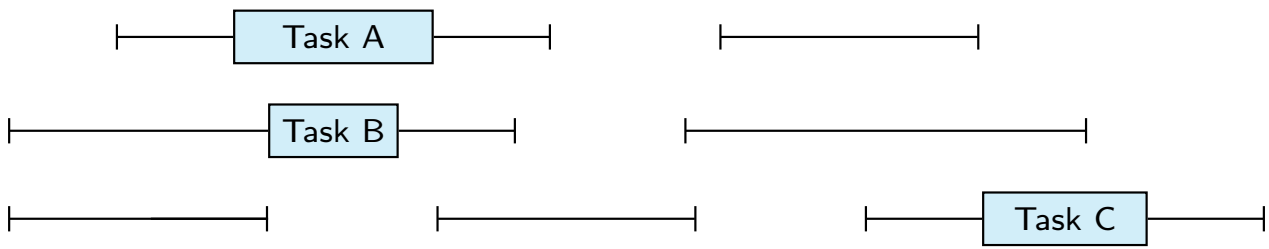
that are feasible with respect to

- Sequencing of tasks on modules
- Precedence constraints between tasks
- Constraints related to the Ethernet network

$\Longrightarrow$ An NP-hard scheduling problem

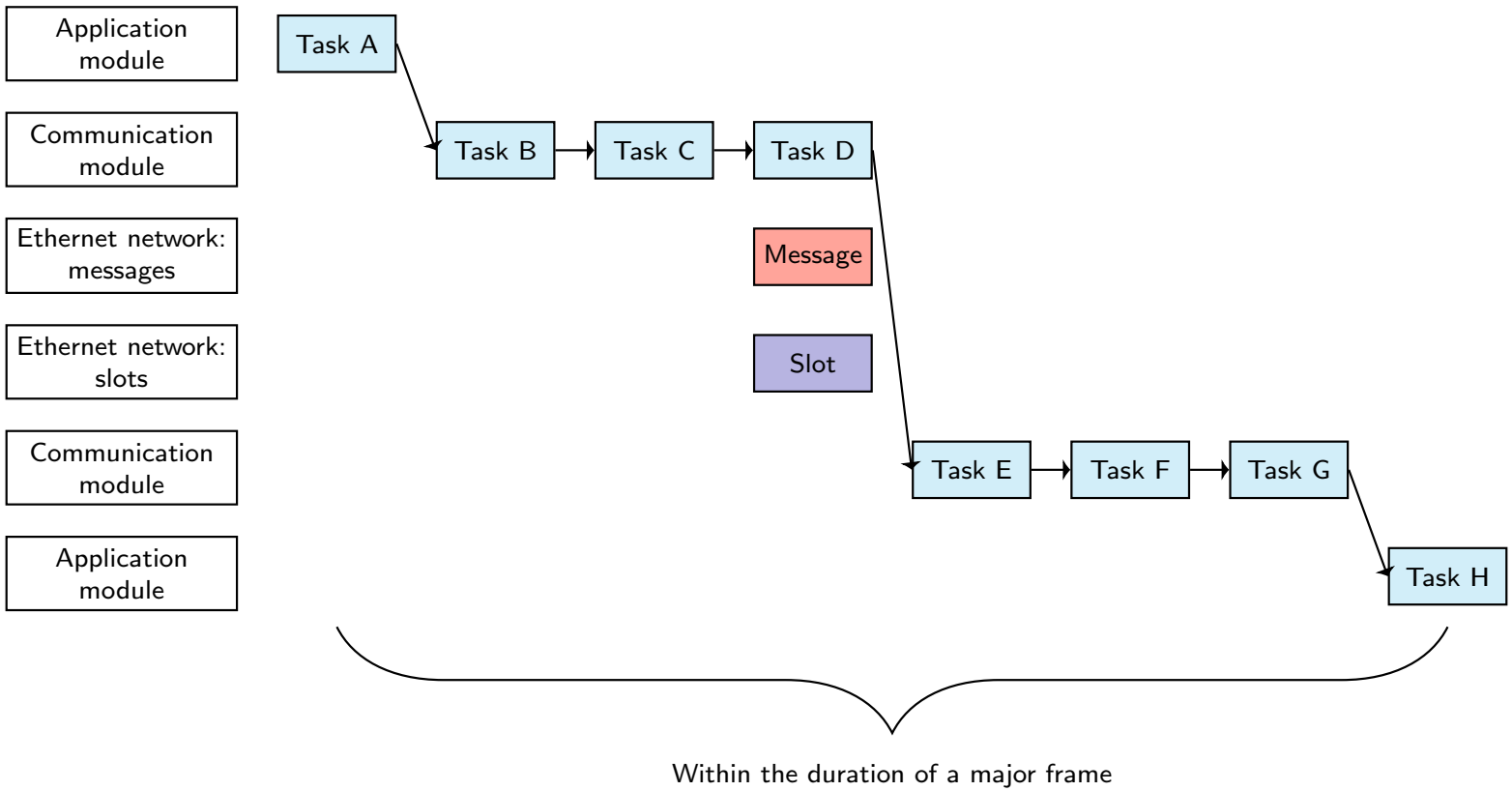
Sequencing of tasks on modules

- Pre-emption of tasks is not allowed
- No overlap between tasks on the same module
- No migration of tasks between modules
- Multiple release time/deadline pairs for each task
- Each task must be scheduled within one of its release-time/deadline pair



Precedence constraints between tasks

Two types of precedence constraints: **chains** and dependencies



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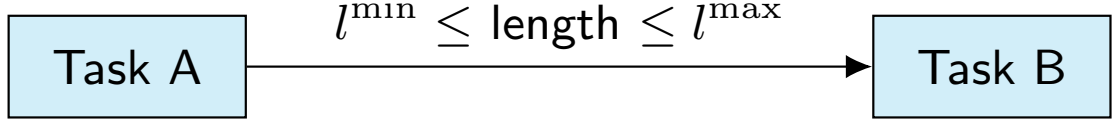
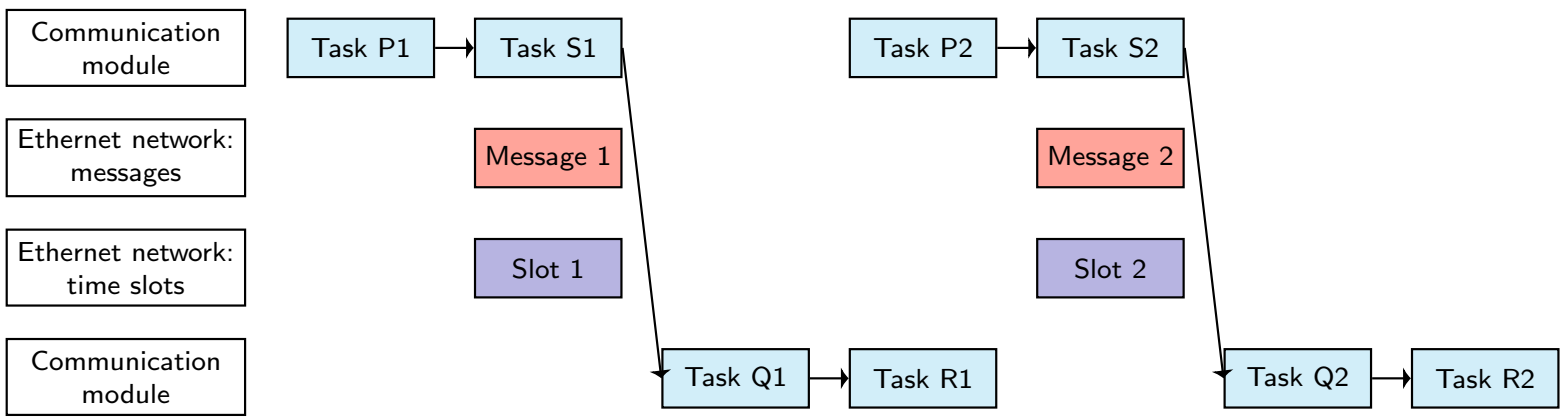


Constraints related to the Ethernet network

- Each message is sent/received by a series of tasks
- Messages must be dequeued in the order they are sent
- There are release time/deadline requirements on involved tasks depending on which time slot a message is sent
- Each slot has a given capacity to send messages
- There are merging requirements on involved tasks if messages are co-allocated



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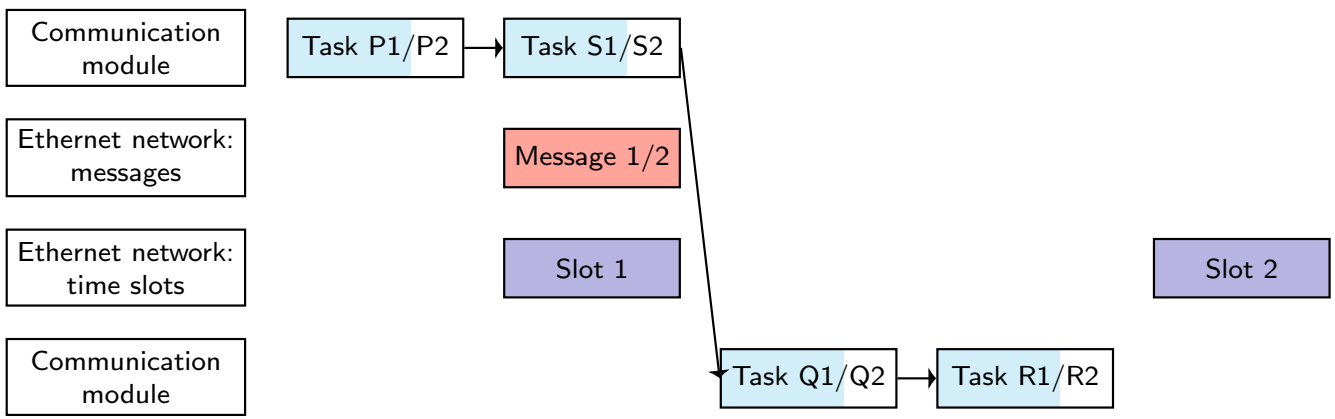


Characteristics of the problem

- There are many tasks to schedule on the communication modules
- There are many messages to send on the Ethernet network
- Assigning messages to time-slots effect the tasks on the communication modules
- Two types of instances: Saab instances and public instances

Instances

Instance	No. modules	No. tasks	No. messages	No. tests
Instance I	4	6 538	64	5
Instance V	6	26 268	1 032	5
Instance VI	18	45 026	2 616	5
Category A*	4.3	4 932	172	30
Category C*	8.9	20 037	908	30
Category D*	17.6	41 655	1 923	30

Table: Instances

* Public instances at: `https://gitlab.liu.se/eliro15/avionics_inst`

How to solve NP-hard problems?

Common techniques to solve NP-hard problems are

Exact approaches: *integer programming, constraint programming, boolean satisfiability, branch and bound, dynamic programming, decomposition, constraint generation, etc.*

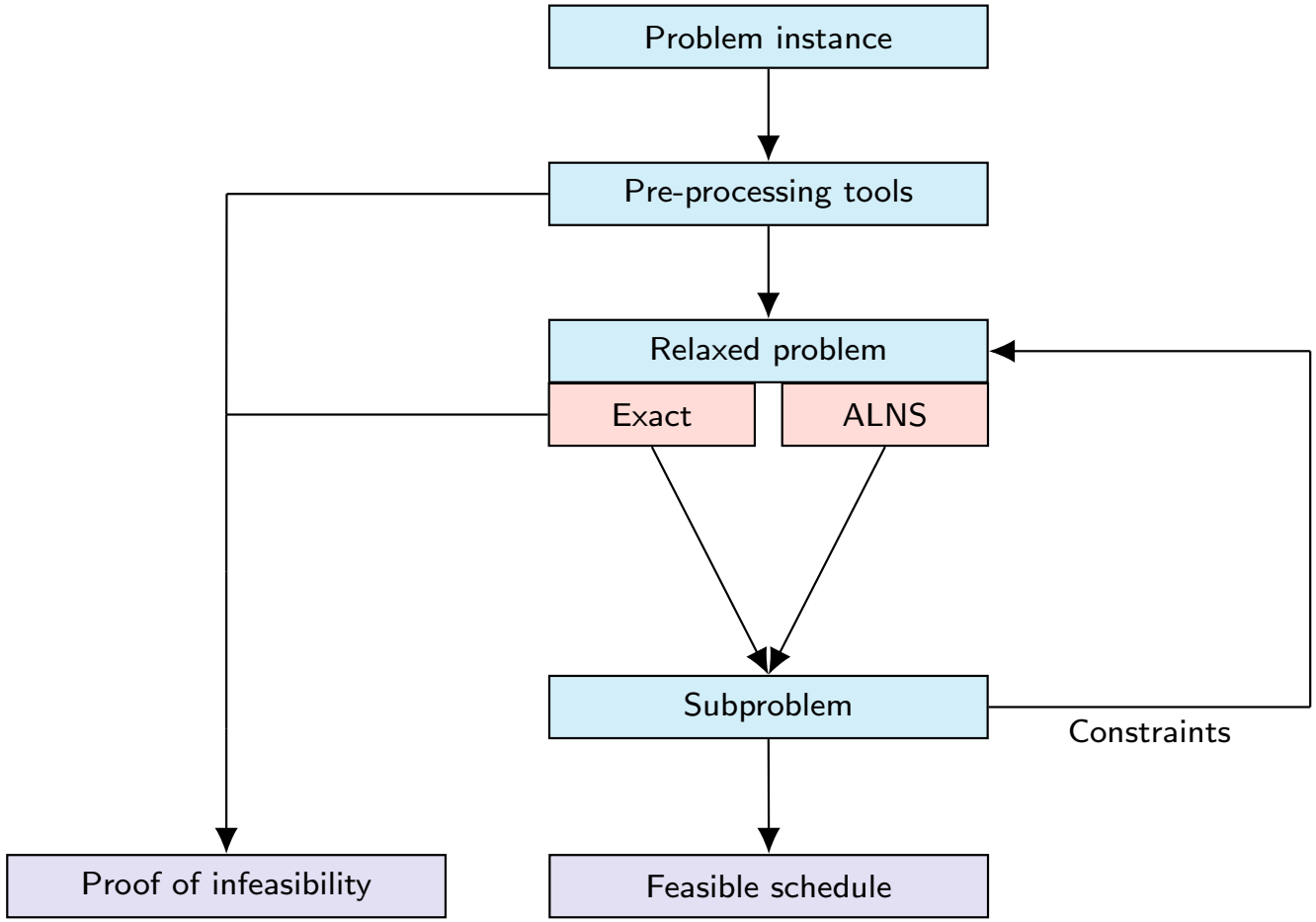
and

Heuristics: *greedy algorithms, local search, metaheuristics, tabu search, large neighbourhood search, simulated annealing, etc.*

Desirable properties in a solution strategy

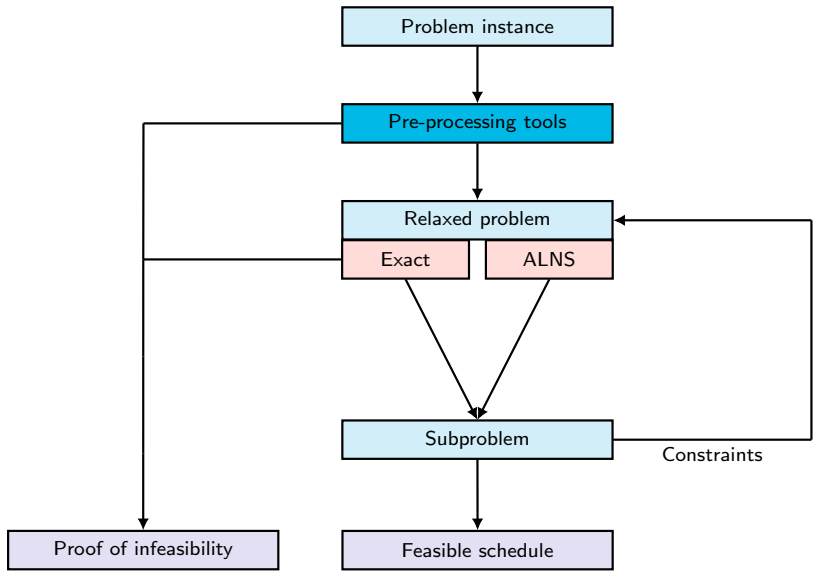
- Re-usability of previously generated information
- Find a feasible schedule if one exists or prove infeasibility
- Suitable for large-scale problem instances

Solution strategy overview



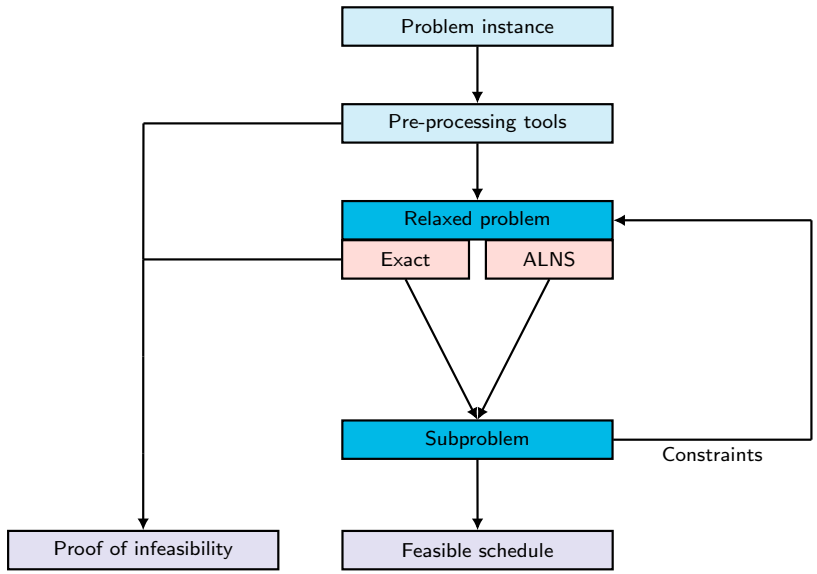
Pre-processing tools

- Constraint propagation to reduce problem size
- Can prove infeasibility quickly if certain constraints never can be fulfilled



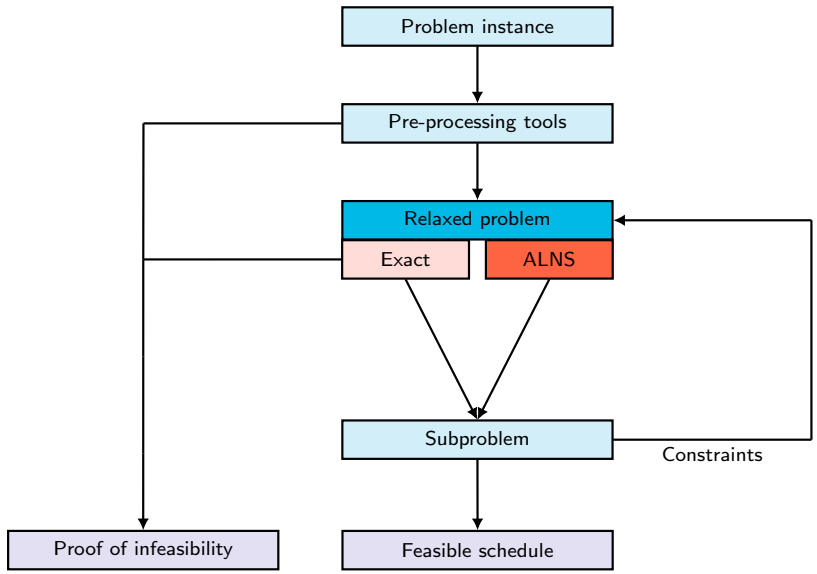
Constraint generation

- A relaxed problem is formed by removing certain sequencing constraints
- If the relaxed problem is infeasible the original problem is infeasible
- Reusing information between similar instances
- Theoretical convergence
- In practise we rely on not generating too many constraints



Heuristic enhancements

- An adaptive large neighbourhood search to solve the relaxed problem
- Iteratively solves integer programming models to improve the current solution
- Decreased ability to prove infeasibility for the relaxed problem



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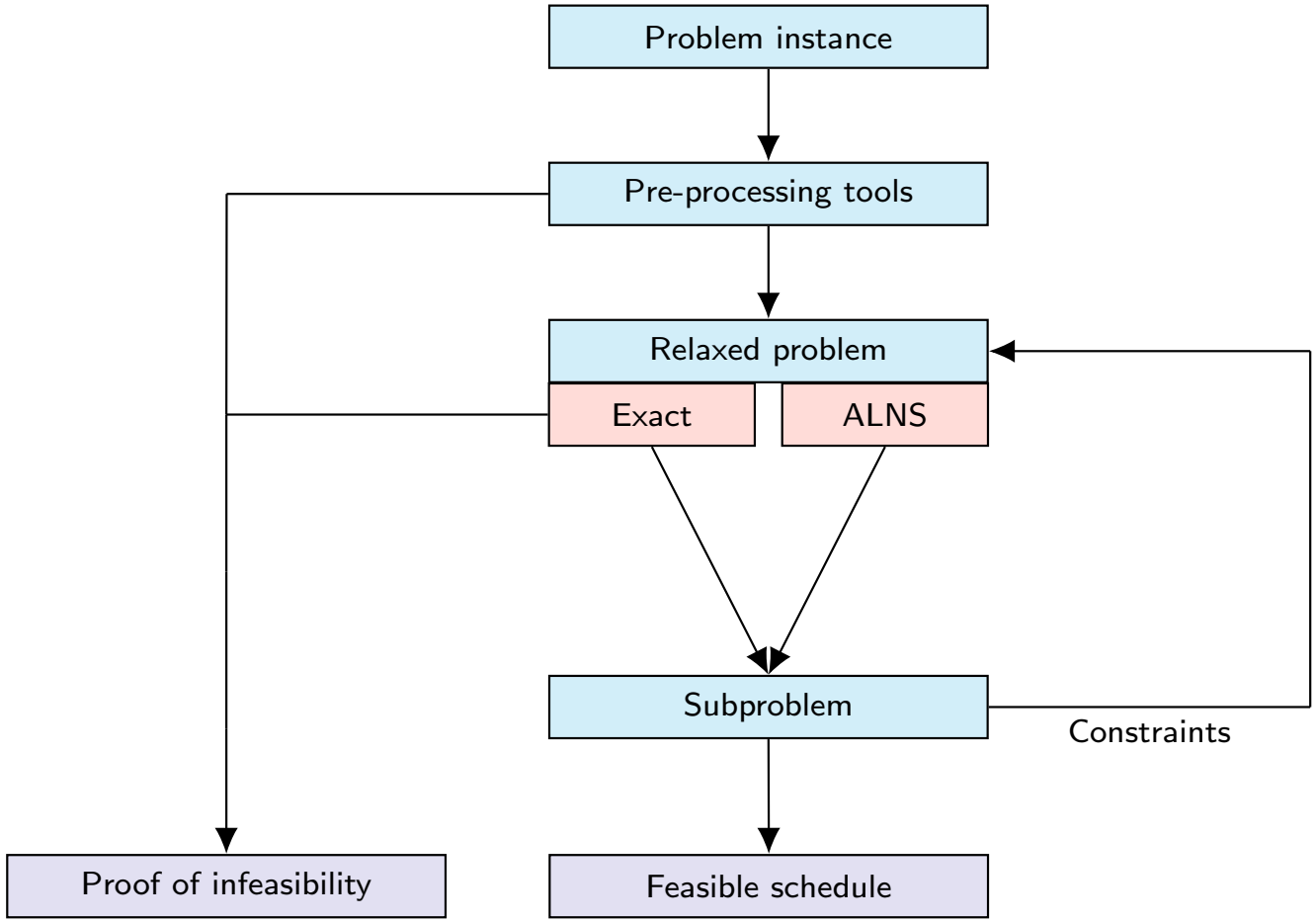

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Comparison of exact approach and ALNS

Instance	No. modules	No. tasks	Time limit	Exact	ALNS
Instance I	4	6 538	6 hours	**5/5**	**5/5**
Instance V	6	26 268	36 hours	0/5	**5/5**
Instance VI	18	45 026	72 hours	0/5	**5/5**
Category A*	4.3	4 932	6 hours	**30/30**	**30/30**
Category C*	8.9	20 037	48 hours	15/30	**28/30**
Category D*	17.6	41 655	72 hours	7/30	**28/30**

Table: Instances

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Summary

- A joint research project between Saab and LiU on scheduling of avionic systems
- An industrially relevant scheduling problem and instances for this problem
- A carefully developed solution strategy that can solve large-scale problem instances

Publication list

- M. Blikstad, E. Karlsson, T. Lööw, E. Rönnberg. An optimisation approach for pre-runtime scheduling of tasks and communication in an integrated modular avionic system. Optimization and Engineering, 19:977—1004, 2018.
- E. Karlsson, E. Rönnberg, A. Stenberg, H. Uppman. Heuristic enhancements of a constraint generation procedure for scheduling of avionic systems. In E. K. Burke, L. Di Gaspero, B. McCollum, N. Musliu, E. Özcan (eds.) PATAT 2018: Proceedings of the 12th International Conference of the Practice and Theory of Automated Timetabling, pp. 417—419. [extended abstract]
- E. Rönnberg. Co-allocation of communication messages in an integrated modular avionic system. In N. Kliewer, J. F. Ehmke, R. Borndörfer (eds.) Operations Research Proceedings 2017, pp.459-465. Springer International Publishing, Cham, 2018. [short paper]
- E. Karlsson, E. Rönnberg. Explicit modelling of multiple intervals in a constraint generation procedure for multiprocessor scheduling. In N. Kliewer, J. F. Ehmke, R. Borndörfer (eds.) Operations Research Proceedings 2017, pp.567-572. Springer International Publishing, Cham, 2018. [short paper]
- M. Blikstad, E. Karlsson, T. Lööw, E. Rönnberg. A constraint generation procedure for pre-runtime scheduling of integrated modular avionic systems. Proceedings of the 13th Workshop on Models and Algorithms for Planning and Scheduling Problems, 2017. [extended abstract]
- E. Karlsson, E. Rönnberg, A. Stenberg, and H. Uppman. A matheuristic approach to large-scale avionic scheduling. Currently a minor revision for journal publication.
- E. Karlsson. Optimisation-based scheduling of an avionic system. Linköping Studies in Science and Technology Licentiate Thesis No. 1844, Linköping University, 2019.

Thank you for your attention!

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