ECE382N.23: Embedded System Design and Modeling

Lecture 9 – System Synthesis & Decision Making

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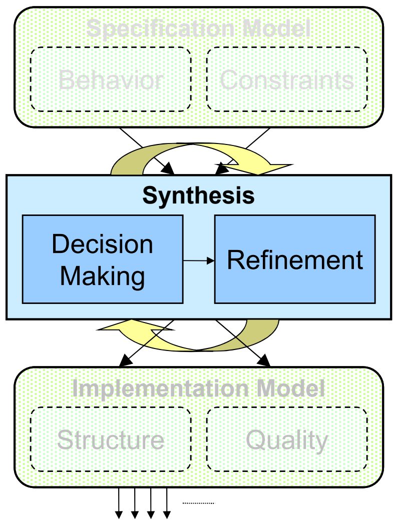
Lecture 9: Outline

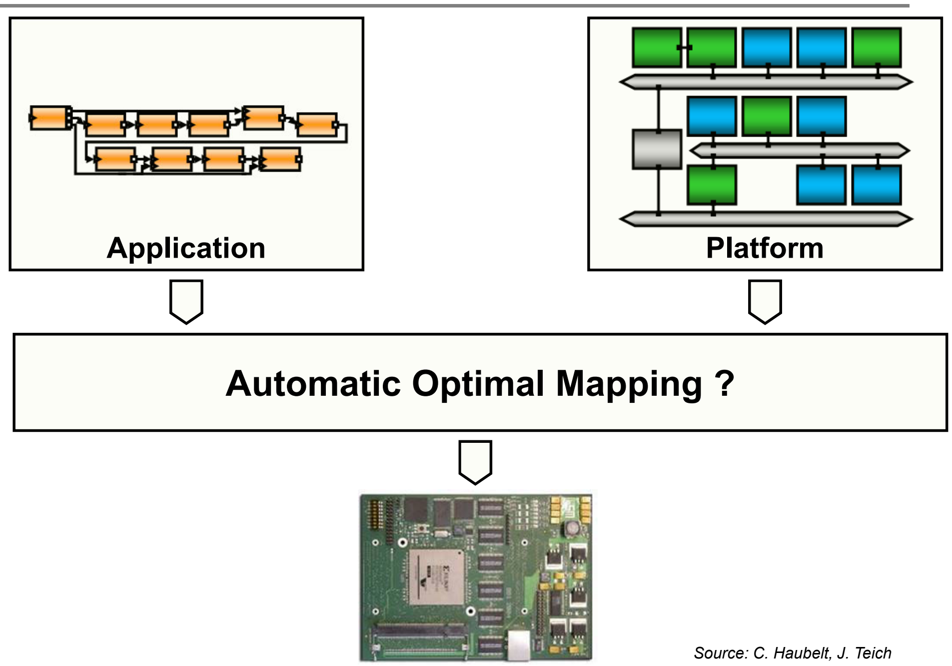
- **Automated decision making**
  - Overview
- **Mapping process**
  - Allocation
  - Partitioning
  - Scheduling
- **Optimization process**
  - Optimization formulation
  - Optimization methods

System Synthesis

- **Decision making**
  - Allocation
  - Mapping
  - Scheduling
- **Refinement**
  - Create and evaluate architecture & cost/quality models



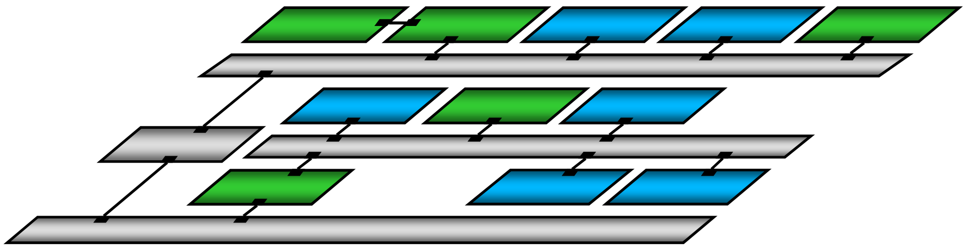
System Synthesis Process



Source: C. Haubelt, J. Teich

Resource Allocation

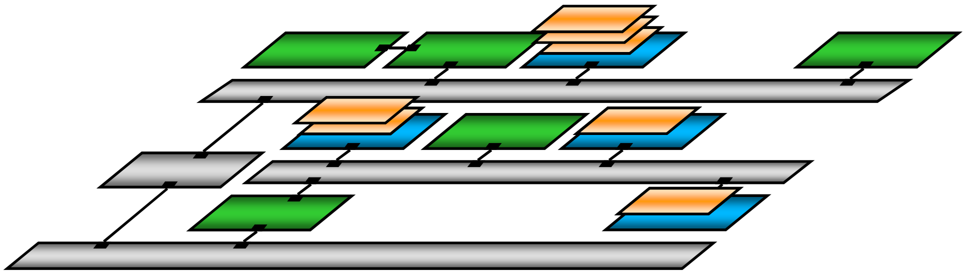
- Resource allocation, i.e., select resources from a platform for implementing the application



Source: C. Haubelt, J. Teich

Process Binding

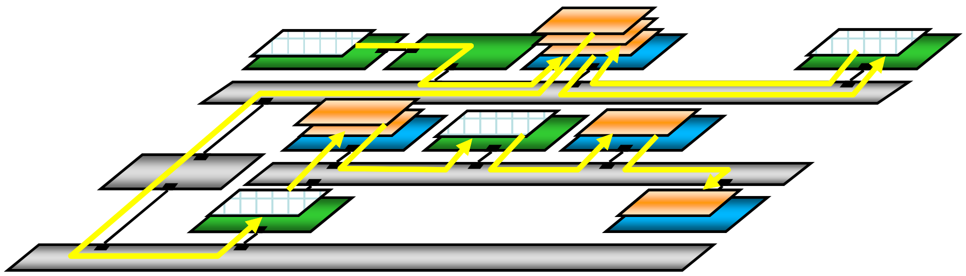
- Process mapping, i.e., bind processes onto allocated computational resources



Source: C. Haubelt, J. Teich

Channel Routing

- **Channel mapping, i.e., assign channels to paths over busses and address spaces**



Source: C. Haubelt, J. Teich

Automated Decision Making

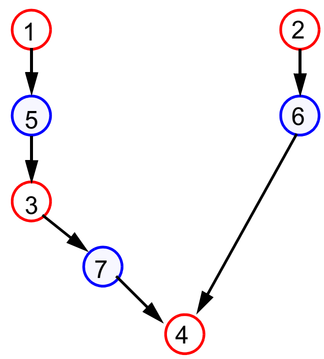
- **Map specification onto architecture**
  - Functionality + constraints ⇨ structure + metrics
- **Synthesis tasks**
  - Allocation
    - Select resources from a platform/architecture template (database)
  - Binding
    - Map processes onto allocated computational resources
    - Map variables onto allocated storage units
    - Route channels over busses, gateways and address spaces
  - Scheduling
    - Determine order of processes bound to the same resource
    - Determine order of transaction routed over the same (arbitration)
  - ➢ Partitioning = (allocation +) binding
  - ➢ Mapping = (allocation +) binding + scheduling

➢ **Formalize & automate the decision making process**

Example (1)

- **Basic model with a task graph MoC and static scheduling**
  - Task graph = homogeneous, acyclic SDF

Application task graph $G_P(V_P, E_P)$



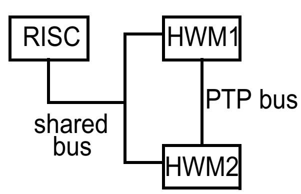
Interpretation:

- V_P consists of functional nodes V_P^f (task, procedure) and communication nodes V_P^c .
- E_P represent data dependencies

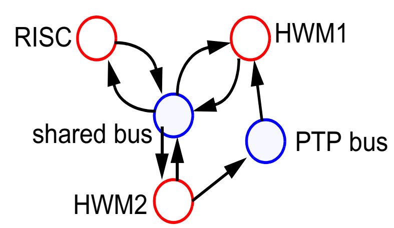
Source: L. Thiele

Example (2)

Architecture graph $G_A(V_A,E_A)$:



Architecture



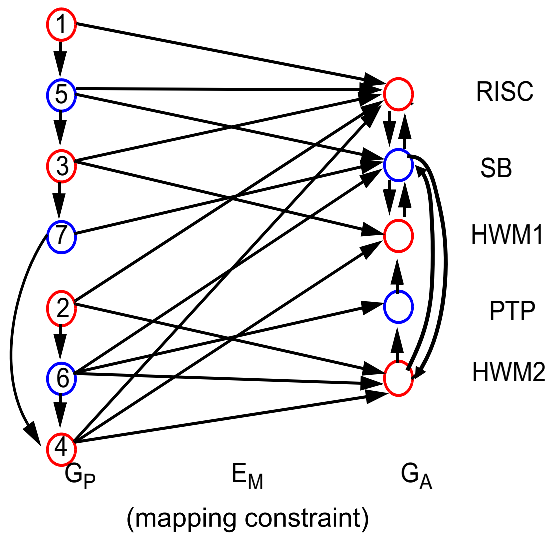
Architecture graph

- V_A consists of functional resources V_A^f (RISC, ASIC) and bus resources V_A^c. These components are potentially allocatable.
- E_A model directed communication.

Source: L. Thiele

Example (3)

Definition: A specification graph is a graph $G_S=(V_S,E_S)$ consisting of a problem graph G_P, an architecture graph G_A, and edges E_M. In particular, $V_S=V_P \cup V_A$, $E_S=E_P \cup E_A \cup E_M$



Source: L. Thiele

Example (4)

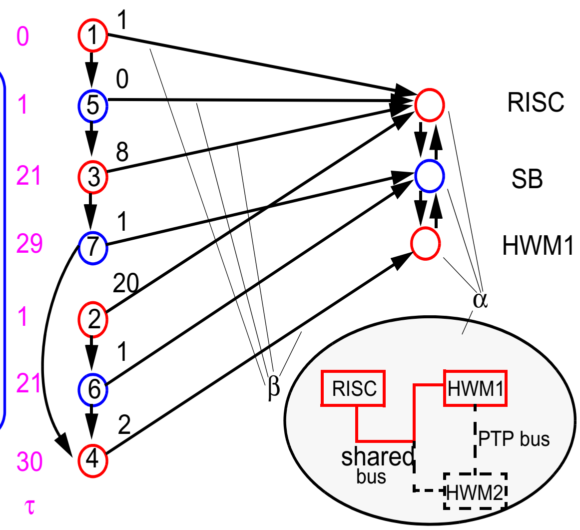
Three main tasks of synthesis:

- Allocation α is a subset of V_A.
- Binding β is a subset of E_M, i.e., a mapping of functional nodes of V_P onto resource nodes of V_A.
- Schedule τ is a function that assigns a number (start time) to each functional node.

Source: L. Thiele

Example (5)

Definition: Given a specification graph G_S an *implementation* is a triple (α,β,τ), where α is a feasible allocation, β is a feasible binding, and τ is a schedule.



Source: L. Thiele

Optimization Problems

- **Decision making under optimization objectives**
  - Single- vs. multi-objective optimization
  - Couple with refinement for full synthesis
- **General optimization formulation**
  - Decision variables: $x \in$ *Domain*
  - Constraints: $g_i(x) \le G_i$, $h_j(x) = H_j$
  - Objective function: $f(x)$: *Domain* $\rightarrow \mathbb{R}$
  - Single-objective optimization problem:

$$\min_x f(x) \text{ subject to } g_i(x) \le G_i, h_j(x) = H_j$$

- **System-level optimization**
  - Allocation (α), binding (β), scheduling (τ) decisions
  - Under functional and non-functional constraints/objectives
    - Architecture & mapping constraints (G_A, E_m)
    - Design quality constraints & objectives

Cost / Objective Functions

- **Measure quality of a design point as optimization objective**
  - May include C … system cost in [$]
    L … latency in [sec]
    P… power consumption in [W]
- **Example: linear weighted cost function with penalty**

$$f(C, L, P) = k_1 \cdot h_C(C,C_{max}) + k_2 \cdot h_L(L,L_{max}) + k_3 \cdot h_P(P,P_{max})$$

  - h_C , h_L , h_P … denote how strong C, L, P violate the design constraints $C_{max}, L_{max}, P_{max}$
  - k_1 , k_2 , k_3 … weighting and normalization
- **Requires *estimation and/or evaluation* to find C, L, P**
  - Refinement + simulation (evaluation, Lectures 5-6)
  - Analytical quality/cost models (estimation, Lectures 7-8)

Source: L. Thiele

Optimization Methods

- **Exact (optimal) methods**
  - Enumeration, exhaustive search
  - Convex optimizations
  - (Integer) linear programming
  - ➢ Prohibitive for intractable problems (large design spaces)
- **Heuristics (non-optimal)**
  - Constructive
    - Random assignment, list schedulers
  - Iterative
    - Random search, simulated annealing
  - Set-based iterative
    - Evolutionary/genetic Algorithms (EA/GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO)
    - ➢ Multi-objective optimization (MOO), Design space exploration (DSE)

➢ **Exact & constructive methods imply analytical cost models**

Source: C. Haubelt, J. Teich

Lecture 9: Summary

- **System-level synthesis**
  - Automatic decision making + refinement
- **Decision making**
  - Allocation
  - Partitioning
  - Scheduling
- **Optimization**
  - Decision variables, objectives and constraints
  - Cost functions to quantify impact of decisions
  - Single- vs. multi-objective optimization