

EE382N.23: Embedded System Design and Modeling

Lecture 9 – System Synthesis & Decision Making

Andreas Gerstlauer
Electrical and Computer Engineering
University of Texas at Austin
gerstl@ece.utexas.edu

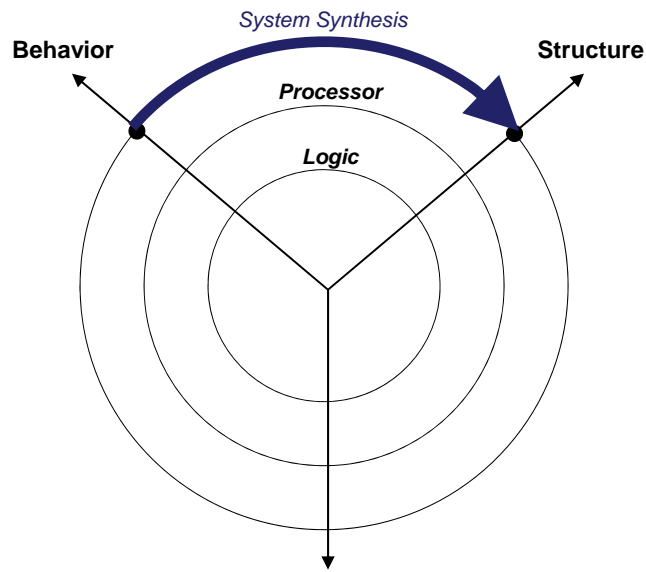


Lecture 9: Outline

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

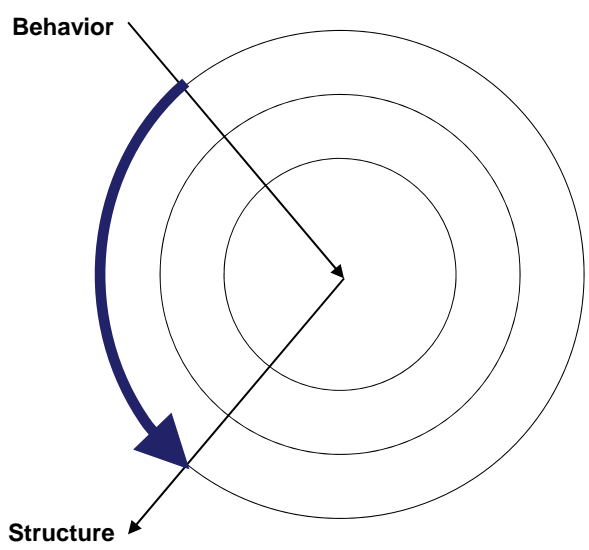
Synthesis

- Gajski's Y-Chart



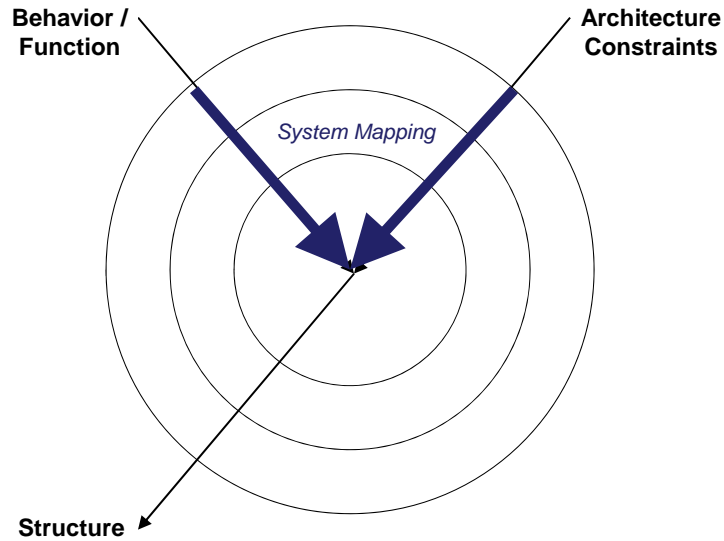
Synthesis

- Gajski's Y-Chart



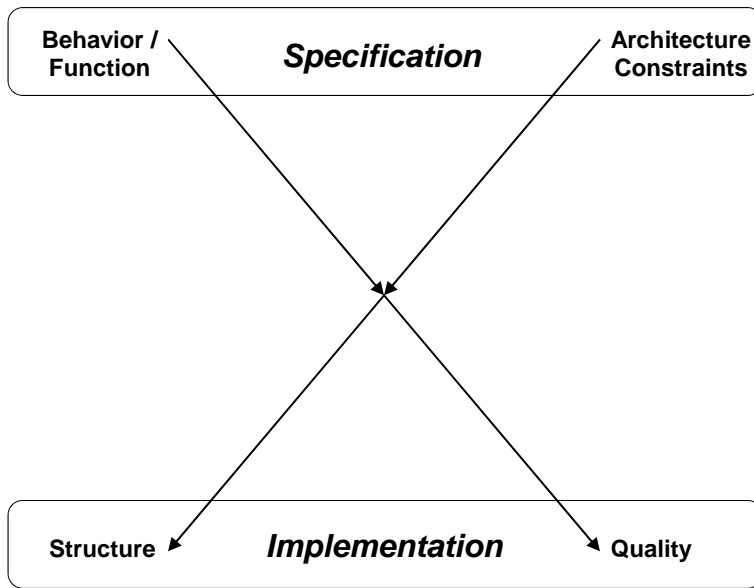
Synthesis

- Platform-based design (the other Y Chart)



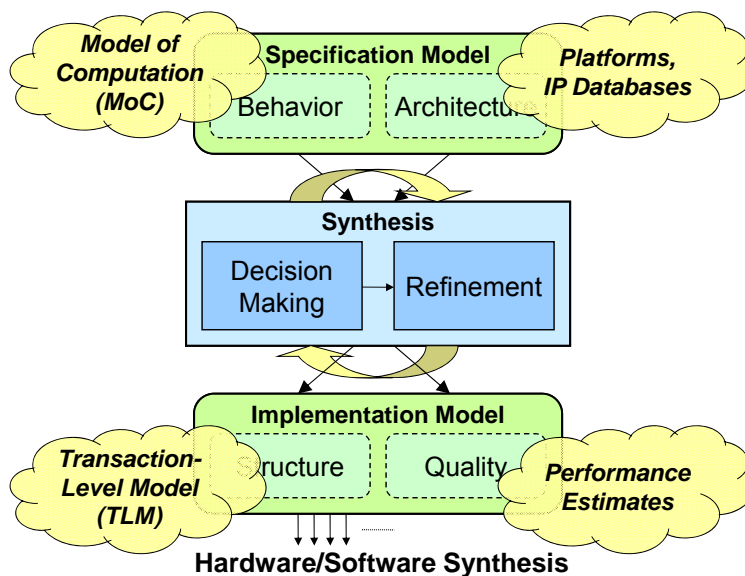
Synthesis

- X-Chart



Synthesis

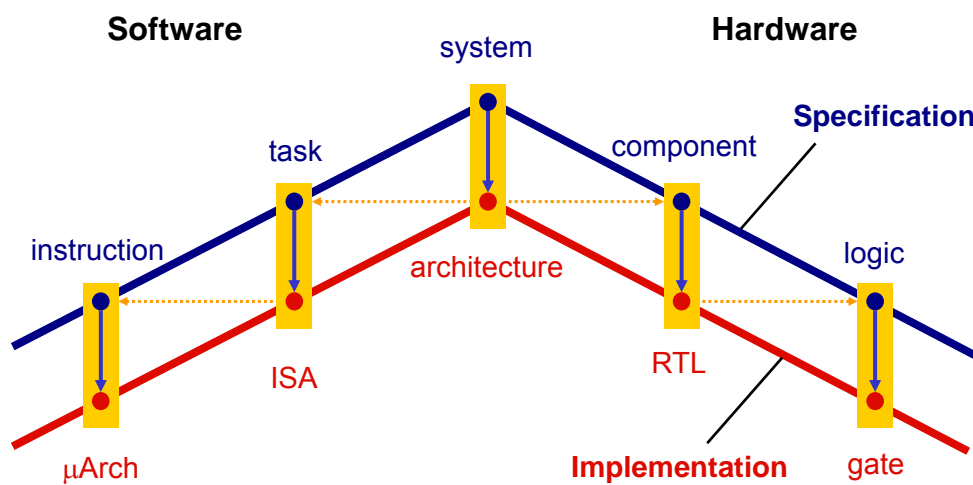
- System-Level Synthesis



Source: A. Gerstlauer, C. Haubelt, A. Pimentel, et al., "Electronic System-Level Synthesis Methodologies," TCAD, 2009.

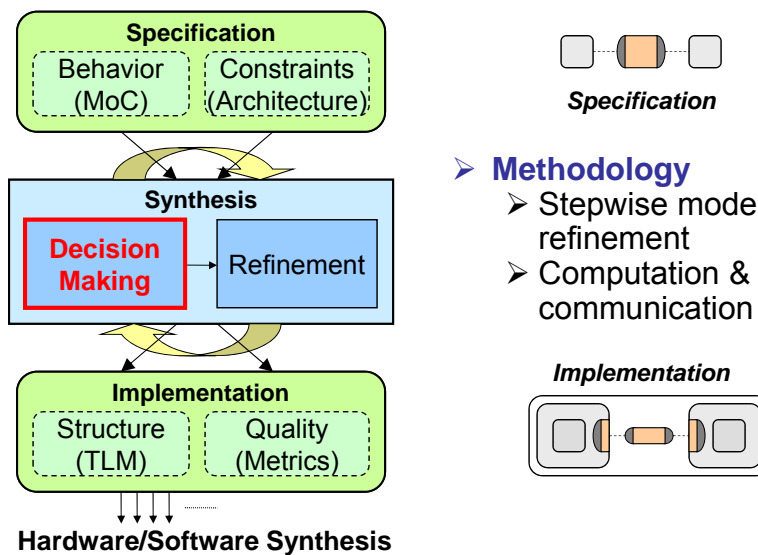
Hardware/Software Synthesis

- Double-roof model

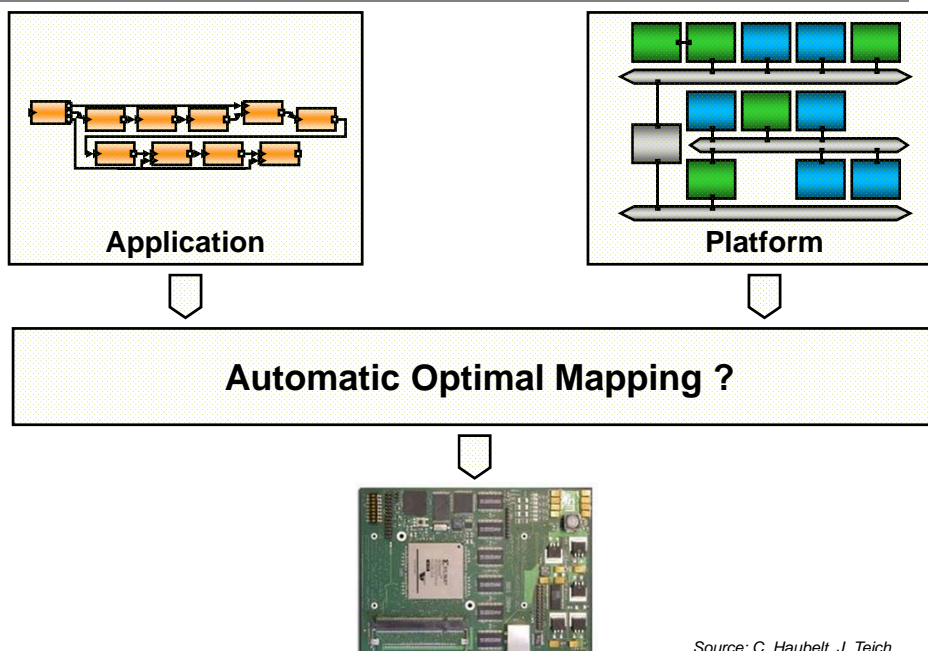


System-Level Synthesis

- X-Chart



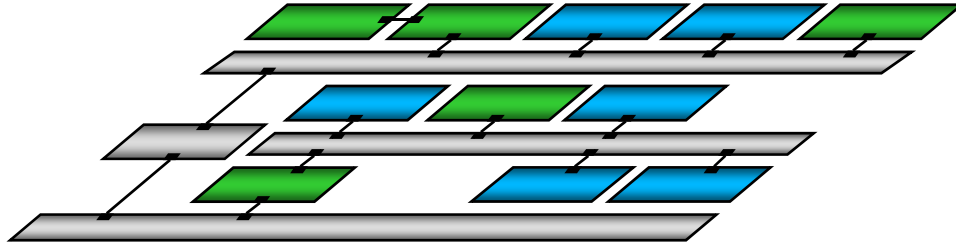
System Synthesis



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

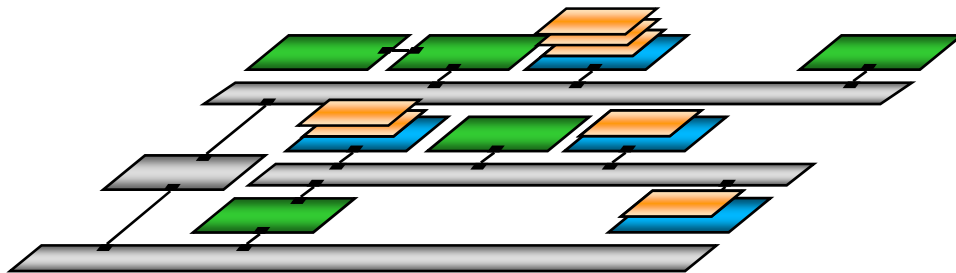
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Process Binding

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



Source: C. Haubelt, J. Teich

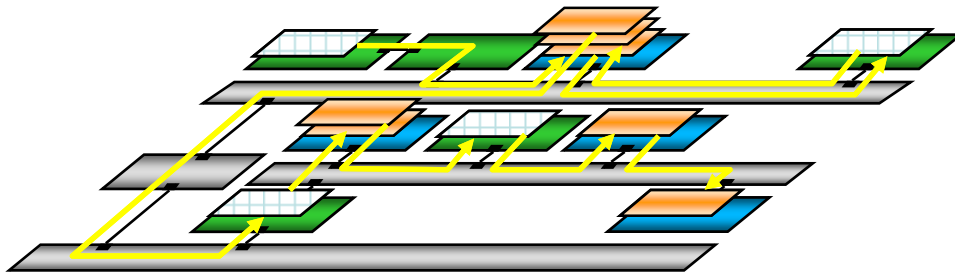
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Channel Routing

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



Source: C. Haubelt, J. Teich

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Automated Decision Making

- Map specification onto architecture
 - Functionality + constraints \Rightarrow 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
- Formalization of decision making process

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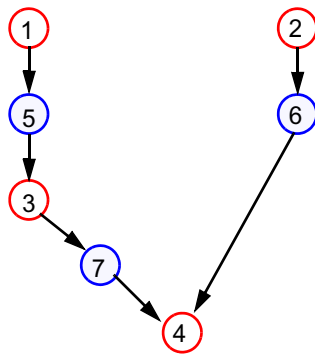
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Example (1)

- **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

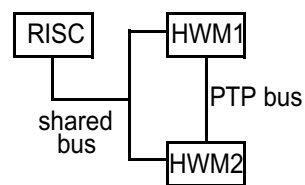
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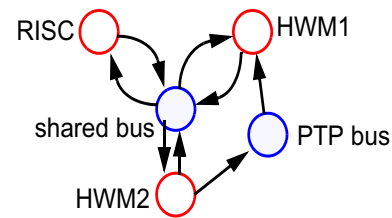
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Example (2)

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

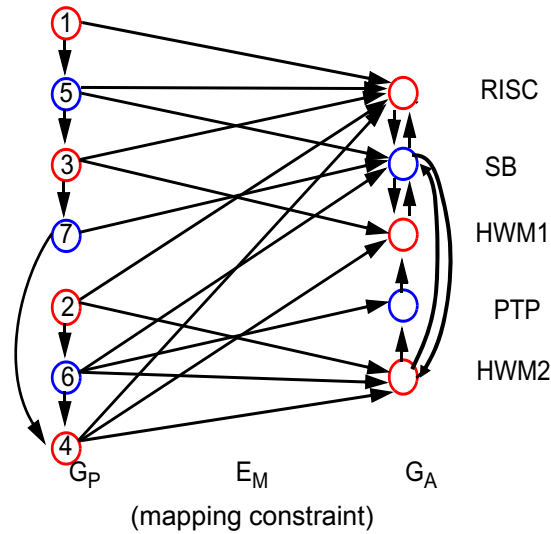
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Example (3)

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

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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

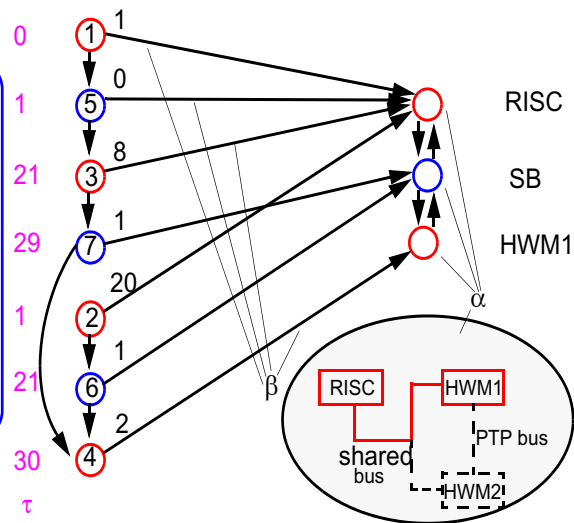
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Example (5)

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

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Optimization

➤ Decision making under optimization objectives

- Single- vs. multi-objective optimization
- Couple with refinement for full synthesis

• General optimization formulation

- Decision variables: $x \in \text{Domain}$
- Constraints: $g_i(x) \leq G_i, h_j(x) = H_j$
- Objective function: $f(x): \text{Domain} \rightarrow \mathbb{R}$
- Single-objective optimization problem:

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

• 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

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Cost 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 or evaluation to find C, L, P**
 - Analytical quality/cost model (estimation, Lecture 11)
 - Refinement + simulation (evaluation, Lectures 7-8)

Source: L. Thiele

Optimization Methods

- **Exact (optimal) methods**

- Enumeration, exhaustive search
- Convex optimizations
- (Integer) linear programming
- Prohibitive for exponential 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