Hardware-Software Codesign

3. Mapping Applications To Architectures

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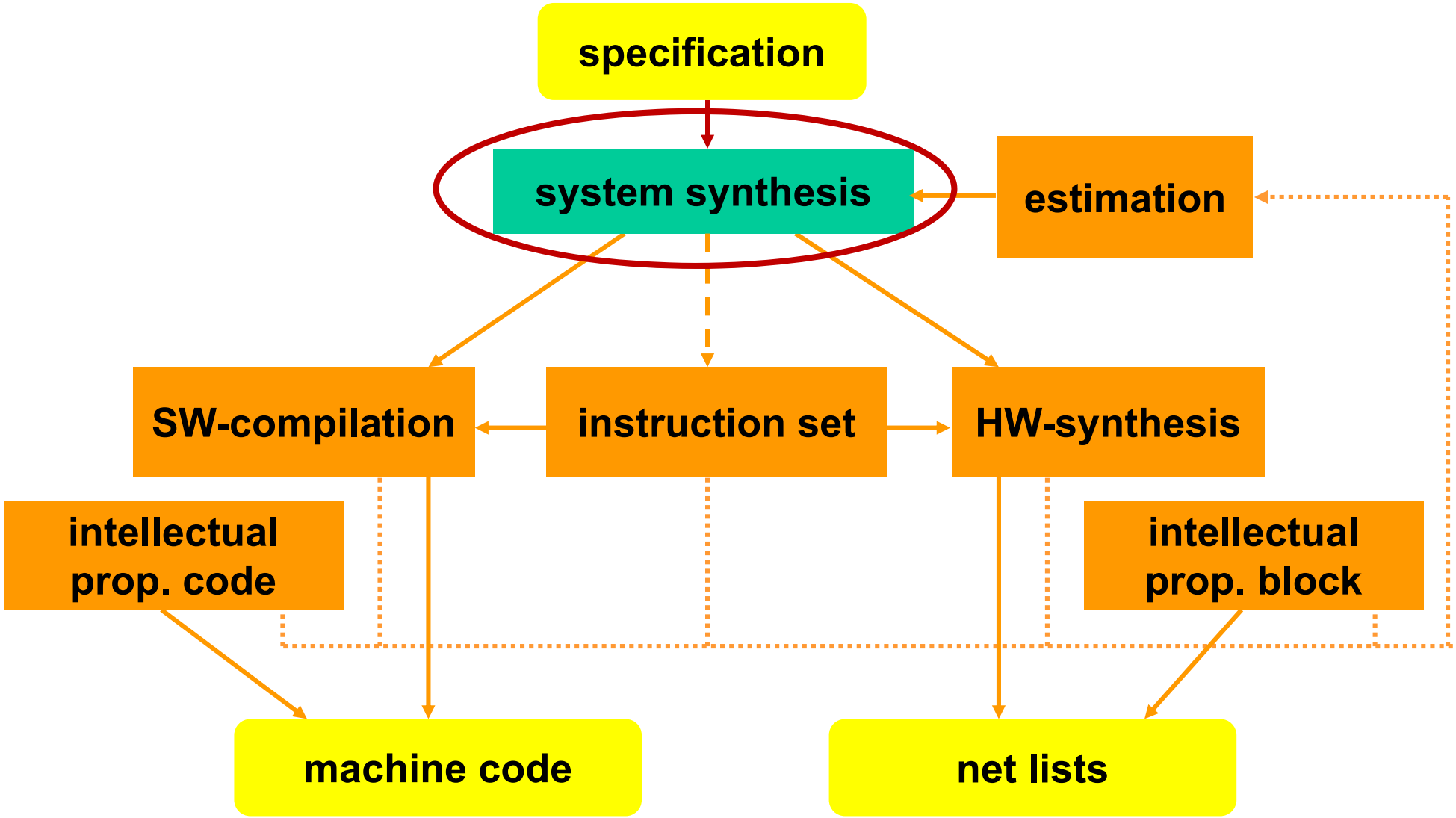
System Design



System Synthesis - Mapping

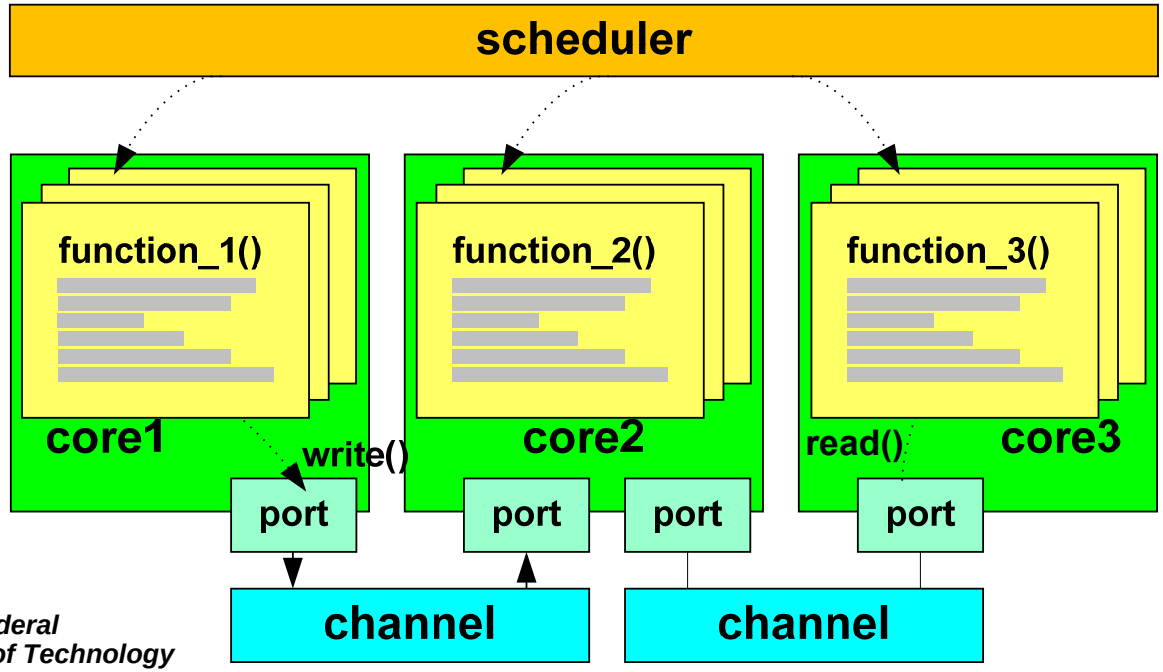
Mapping transforms behavior into structure and execution

- **allocation**: select components
- **binding**: assign functions to components
- **scheduling**: determine execution order

partitioning

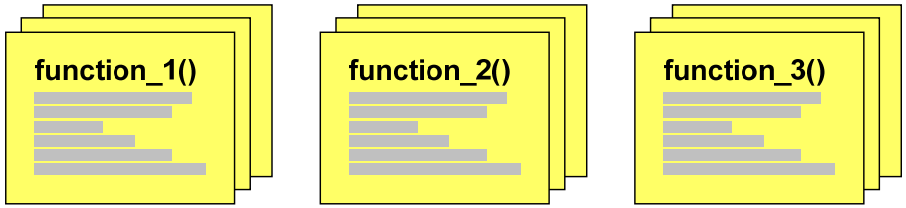
mapping

- … finally, synthesis results into **implementation**



Application Specification

… using an underlying **model of computation**

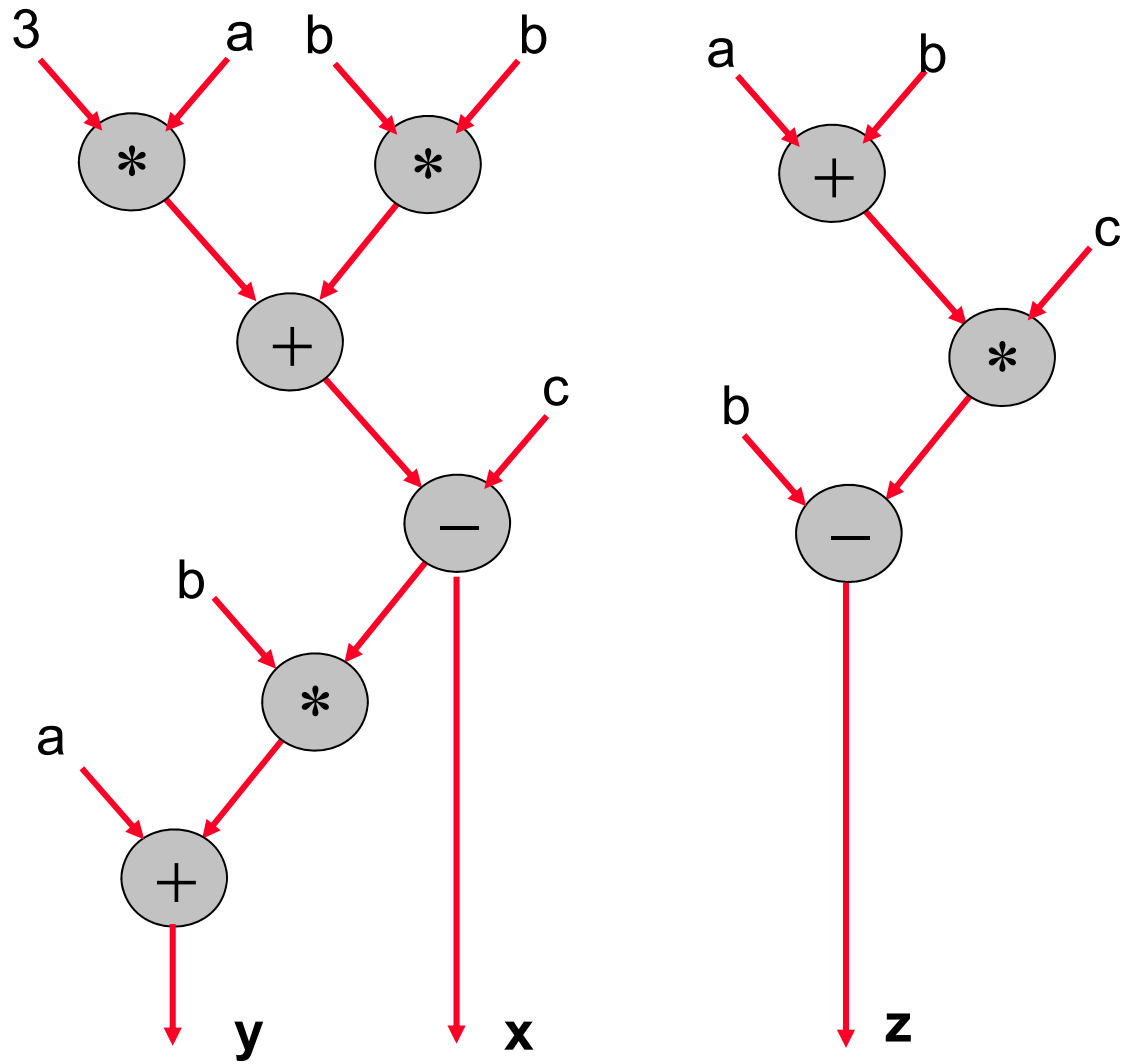


- some examples *(see also next slides)*
  - **task graphs:** data flow graph, control flow graph
  - **process networks:** Kahn process network, synchronous data-flow
  - **state machine representations:** SpecCharts, StateCharts *[not covered in this course]*
- **for mapping**, very often only the ***process network structure*** and its ***(abstract) properties*** are relevant (abstraction from detailed functionality)

Specification Example 1

data flow graph (DFG)

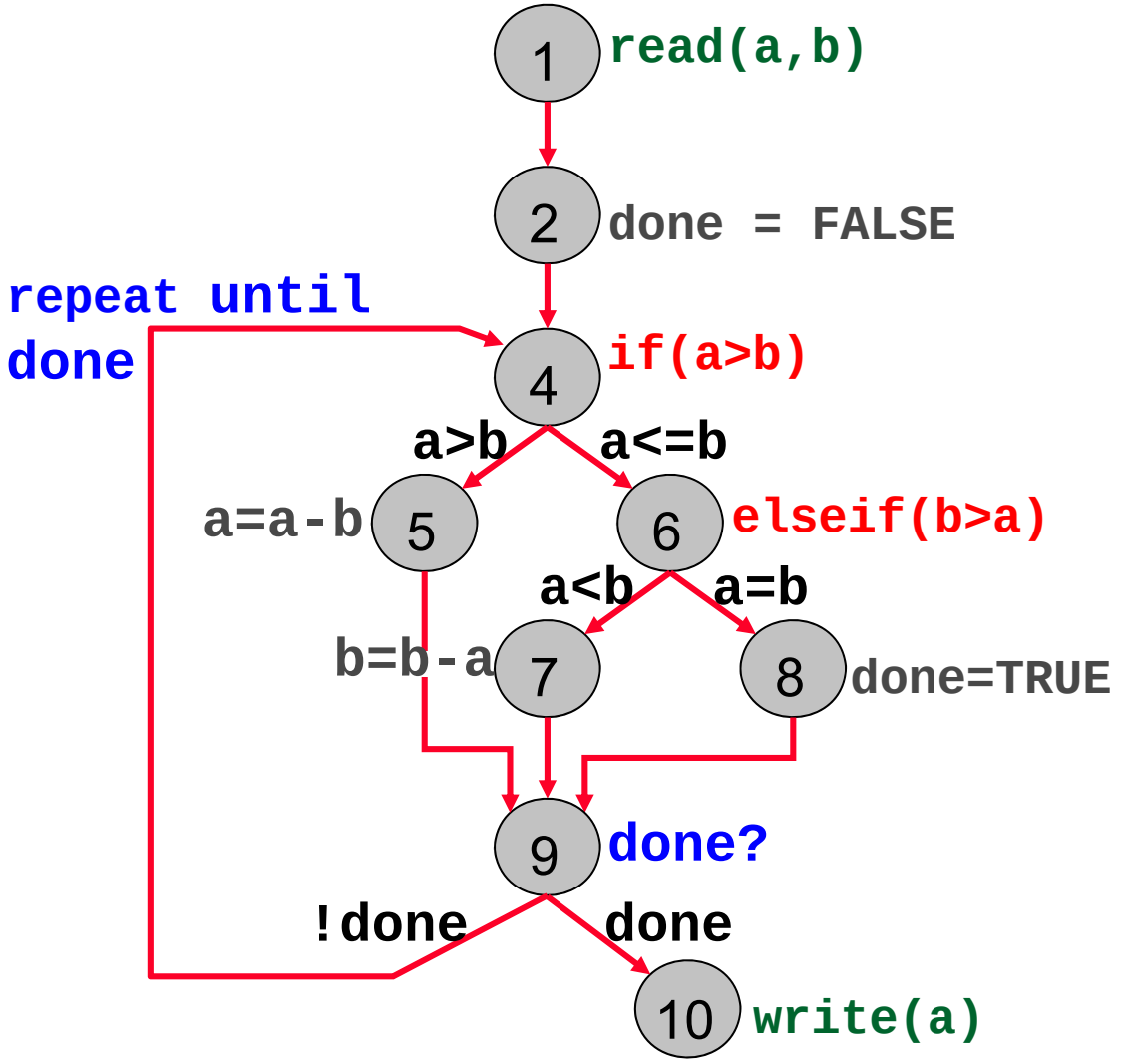
```
x = 3*a + b*b - c;
y = a + b*x;
z = b - c*(a + b);
```



Specification Example 2

control flow graph (CFG)

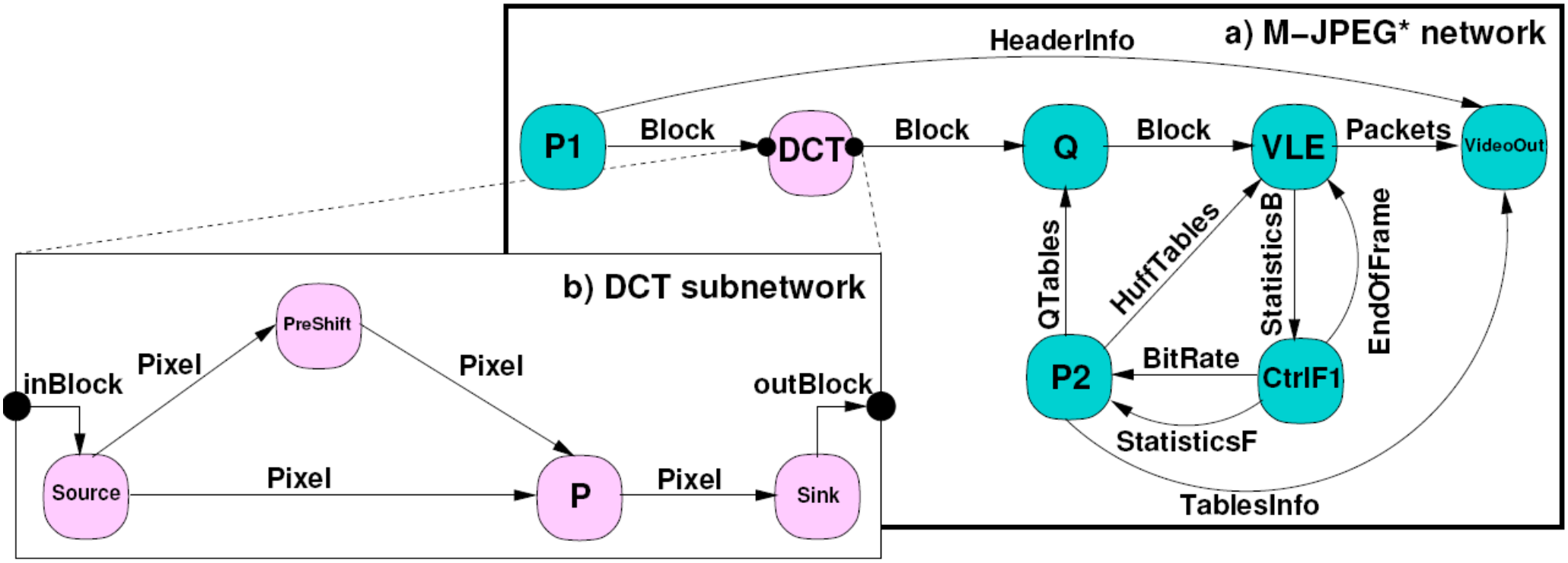
```
   what_is_this {
1      read(a,b);
2      done = FALSE;
3      repeat {
4        if(a>b)
5           a = a-b;
6        elseif(b>a)
7           b = b-a;
8        else done = TRUE;
9      } until done;
10     write(a);
   }
```



Specification Example 3

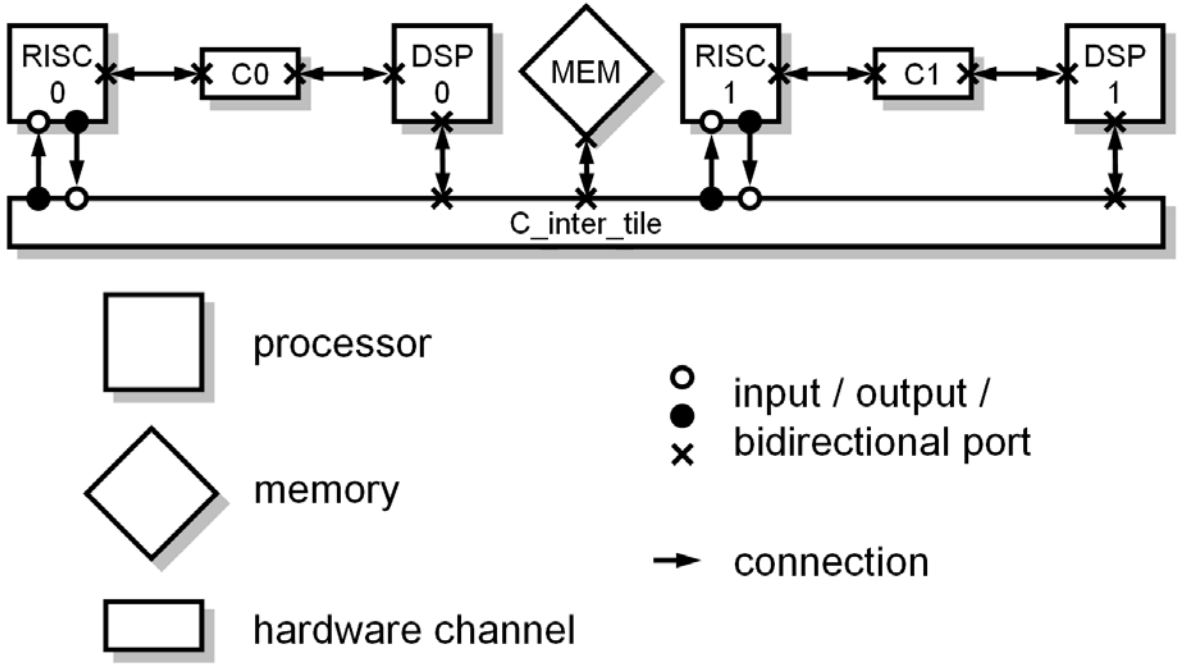
Kahn process network

- *example:* hierarchical network of MJPEG application



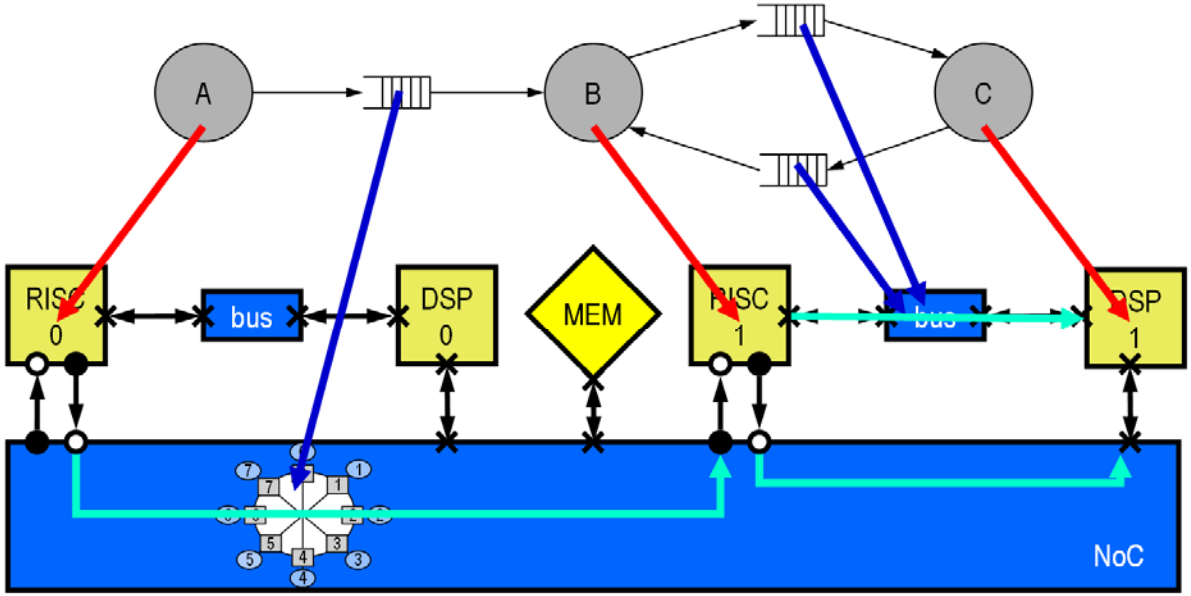
Architecture Specification

- reflects the **structure** and (key) **properties** of the underlying platform
- … and can be done at **different abstraction levels**
- *example:* ***system-level architecture specification***
  - usually a graph notation is used to describe *structure*
  - annotations to graph elements reflect *properties* of the underlying platform, e.g., processing frequency



Mapping Specification

- **mapping relates application and architecture specifications**
  - ***binds*** processes to processors
  - ***binds*** communication between processes to communication paths of the architecture
  - specifies ***resource sharing disciplines*** and ***scheduling***

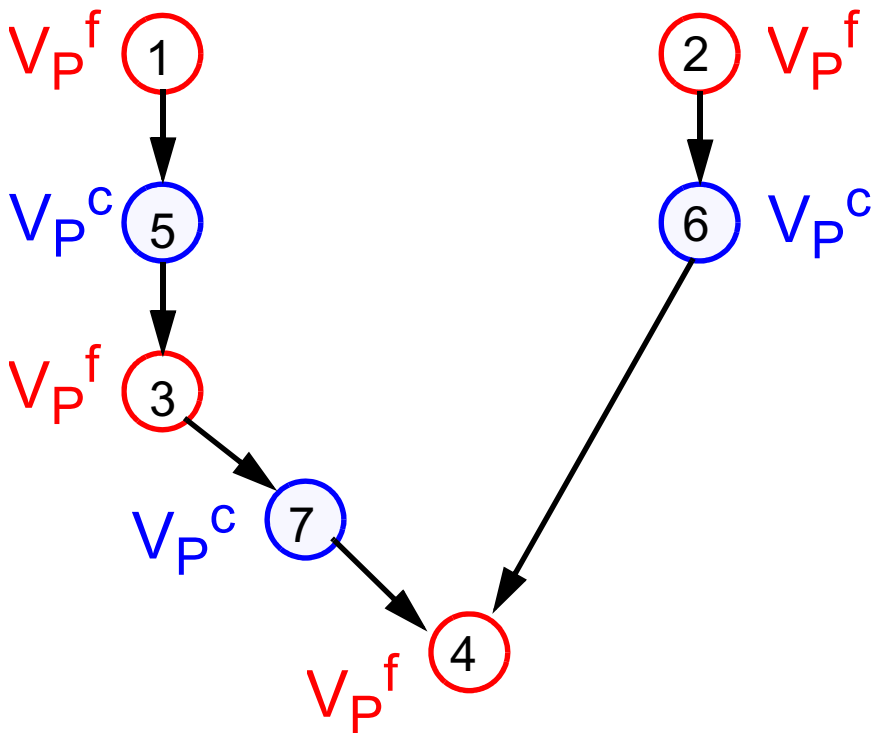


Mapping = binding + scheduling

Example DFG Application Model

- basic model: data flow graph and static scheduling

  data flow graph $G_P(V_P, E_P)$

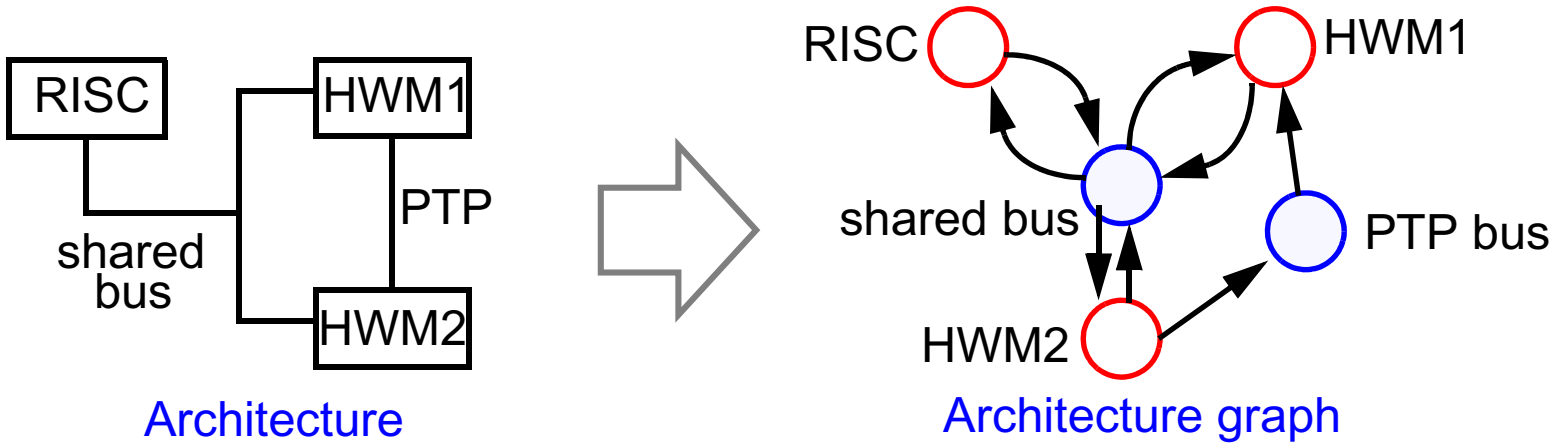


Interpretation:

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

Example Architecture Model

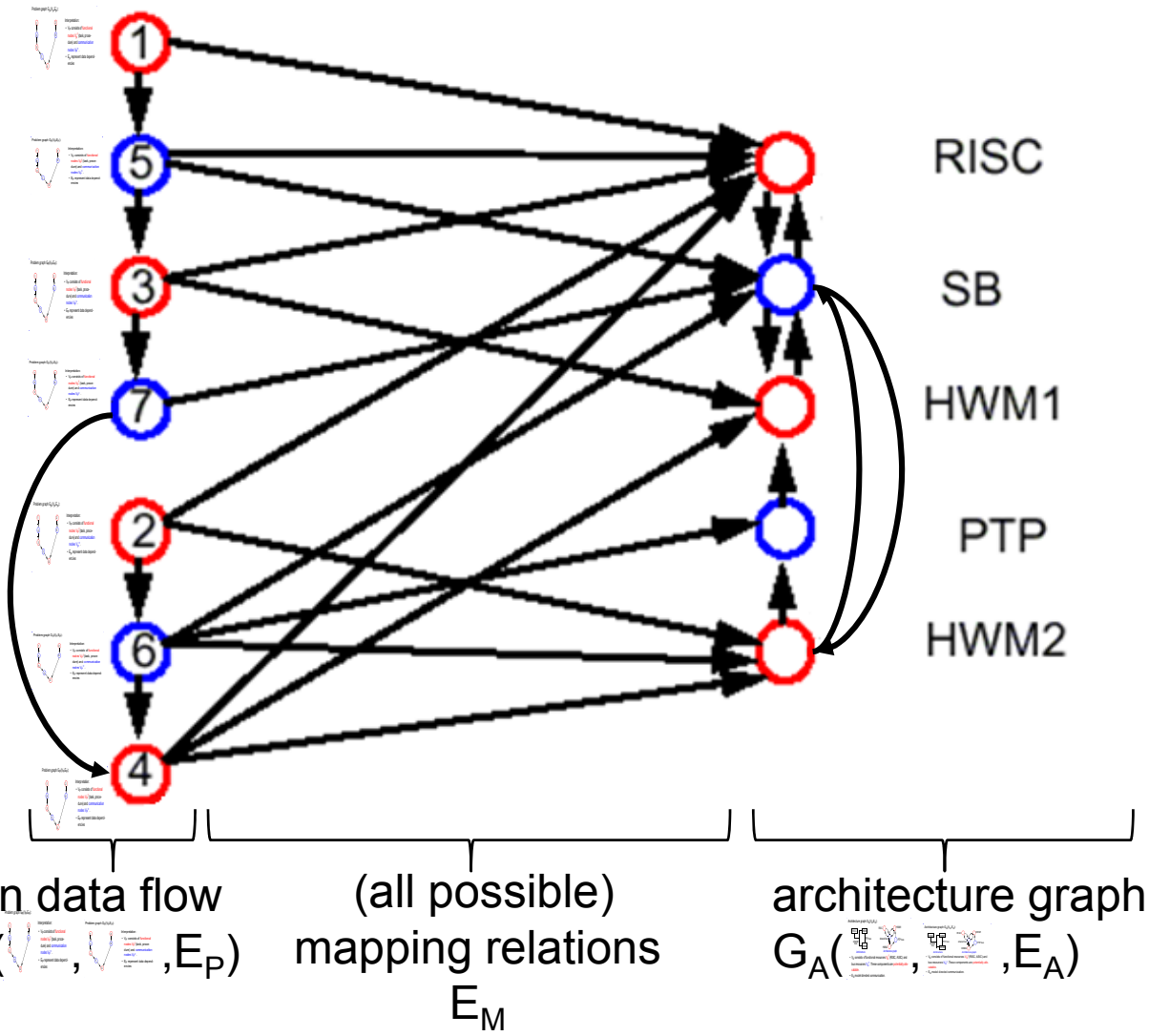
Architecture graph $G_A(V_A,E_A)$:



- 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.

Example Mapping

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



Example Mapping

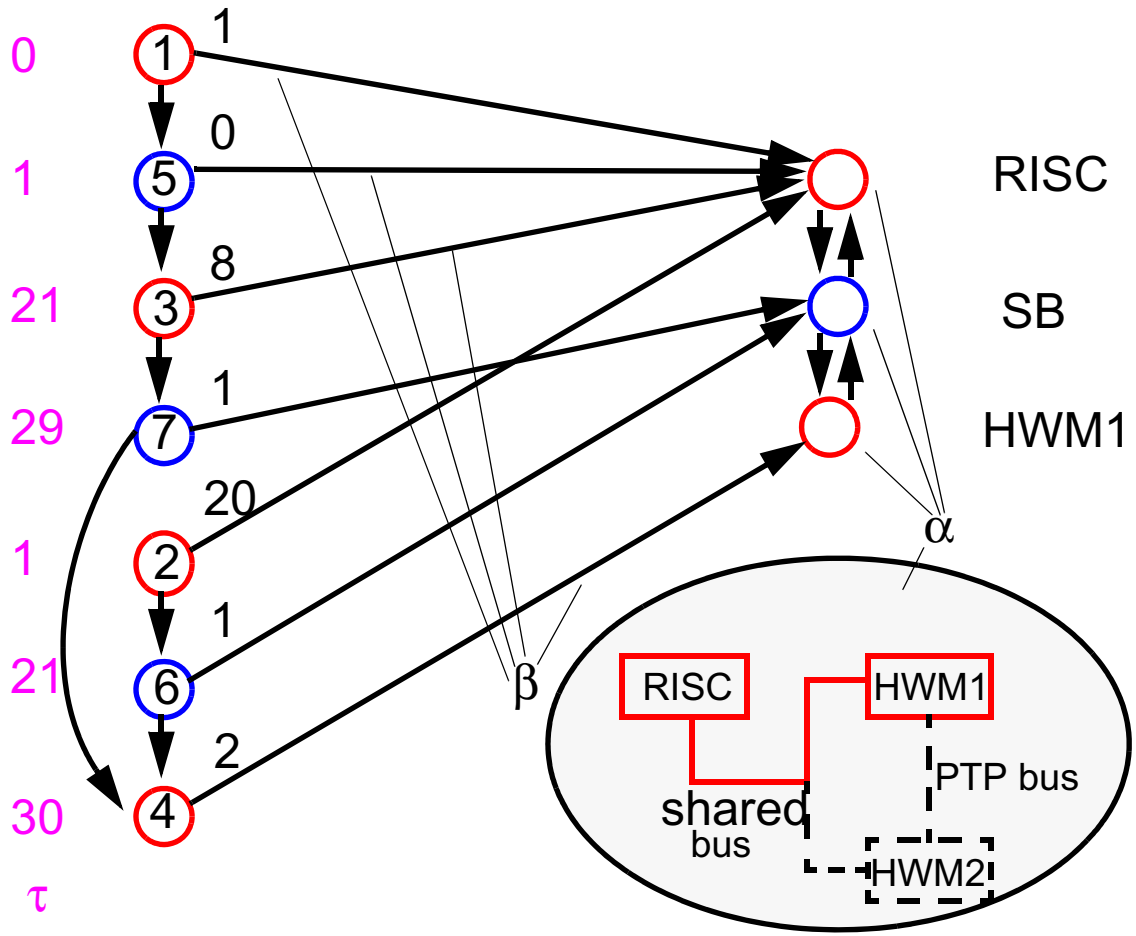
- Mapping involves
  - **allocation α** (subset of $\mathbf{V_A}$)

mapping

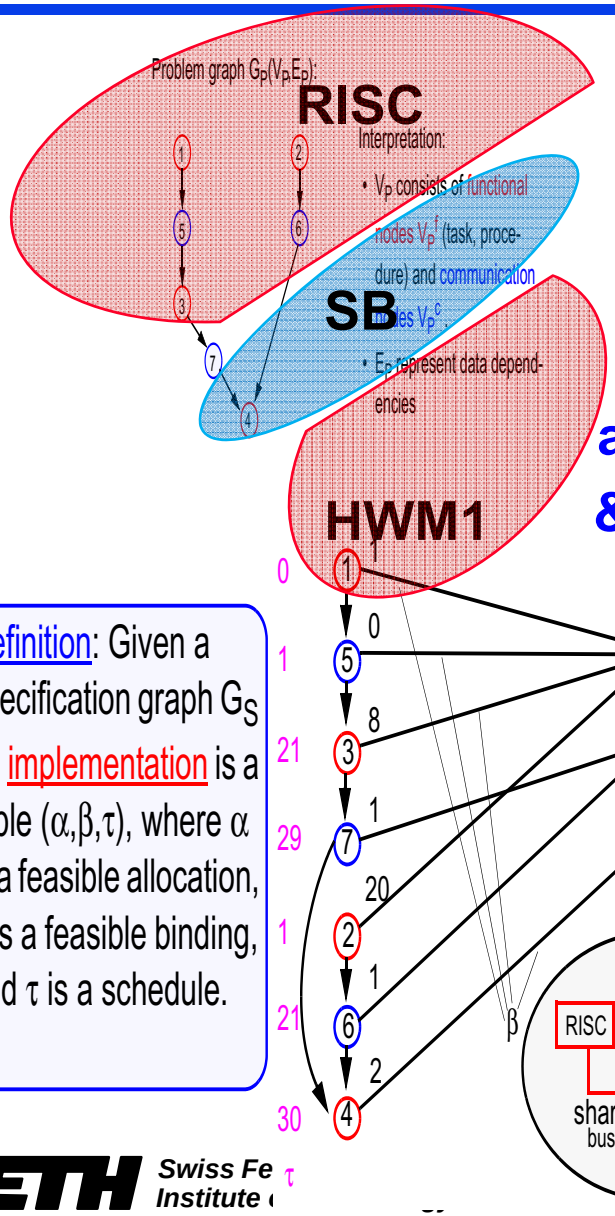
  - **binding β** (subset of $\mathbf{E_M}$), i.e., reflecting the mapping of application nodes in $\mathbf{V_P}$ (functional and communication) onto architectural nodes in $\mathbf{V_A}$ (processors and buses)
  - **scheduling τ**, i.e., assigning an order among nodes (e.g., start time)
  - …and ultimately, **implementation of (α, β, τ)** targeted to actual hardware and/or software modules

Example … towards Implementation

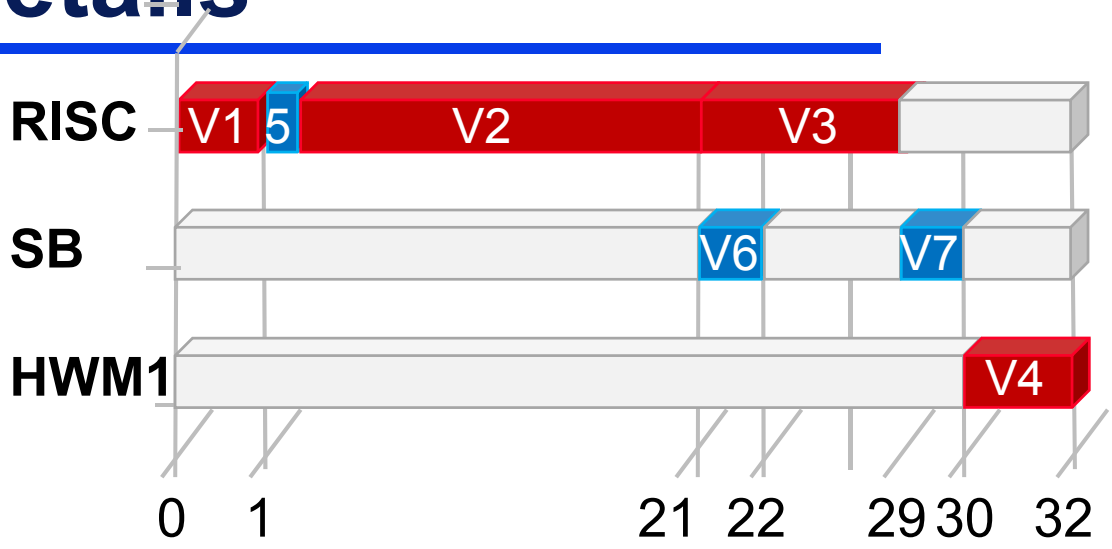
Definition: Given a specification graph G_S an implementation is a triple (α,β,τ), where α is a feasible allocation, β is a feasible binding, and τ is a schedule.



Implementation – Details



application &mapping

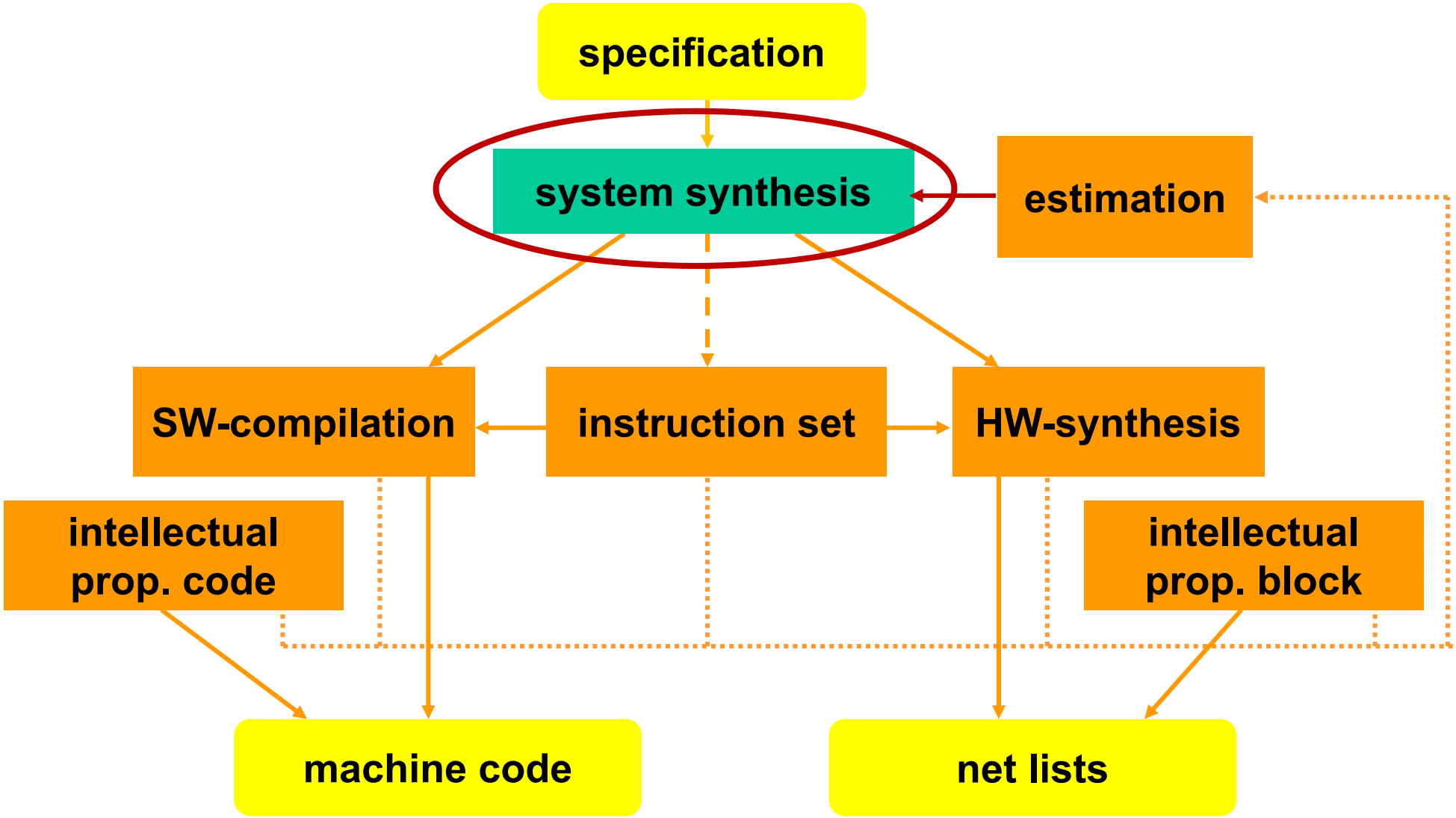


execution schedule

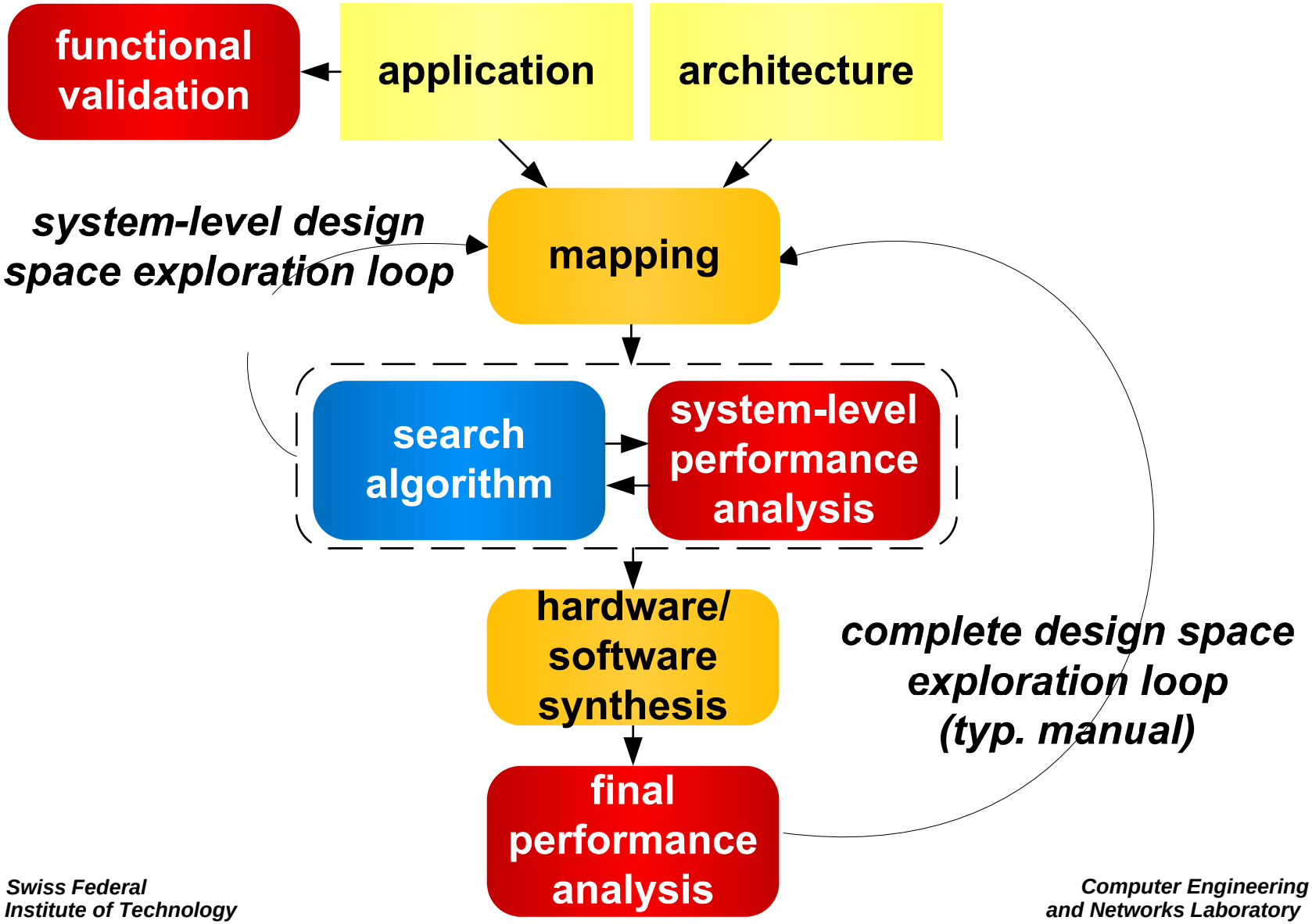
Definition: Given a specification graph G_S an implementation is a triple (α,β,τ), where α is a feasible allocation, β is a feasible binding, and τ is a schedule.

implementation

System Exploration

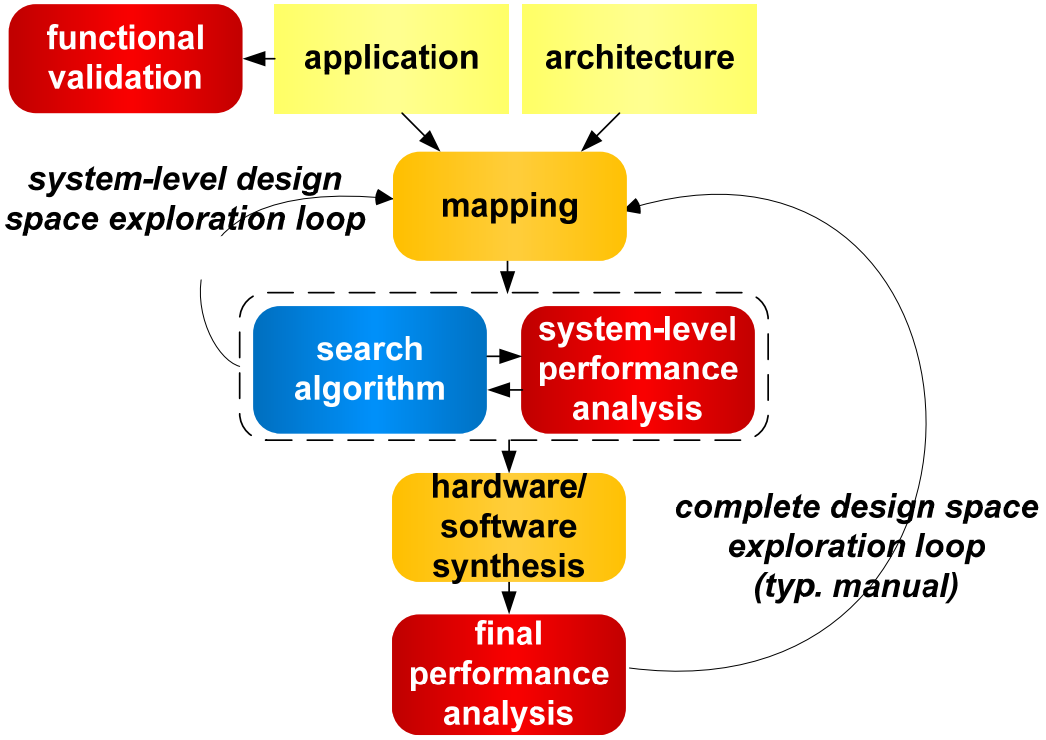


Mapping Optimization in the Design Flow



Optimization via Design Space Exploration

- Often based on iterative interaction between optimization and performance analysis
- Based on quantitative parameters obtained through estimation, e.g., end-to-end delay, throughput, power, temperature



What is ahead?

- ***Section 4: Partitioning***
  - Some basic methods to assign tasks to computing resources (or communication to networks and busses).
- ***Section 5: Multiobjective Optimization***
  - Generic method to optimize H/S systems (and other engineering systems)
- ***Section 7: Design Space Exploration***
  - Application of these methods to design space exploration