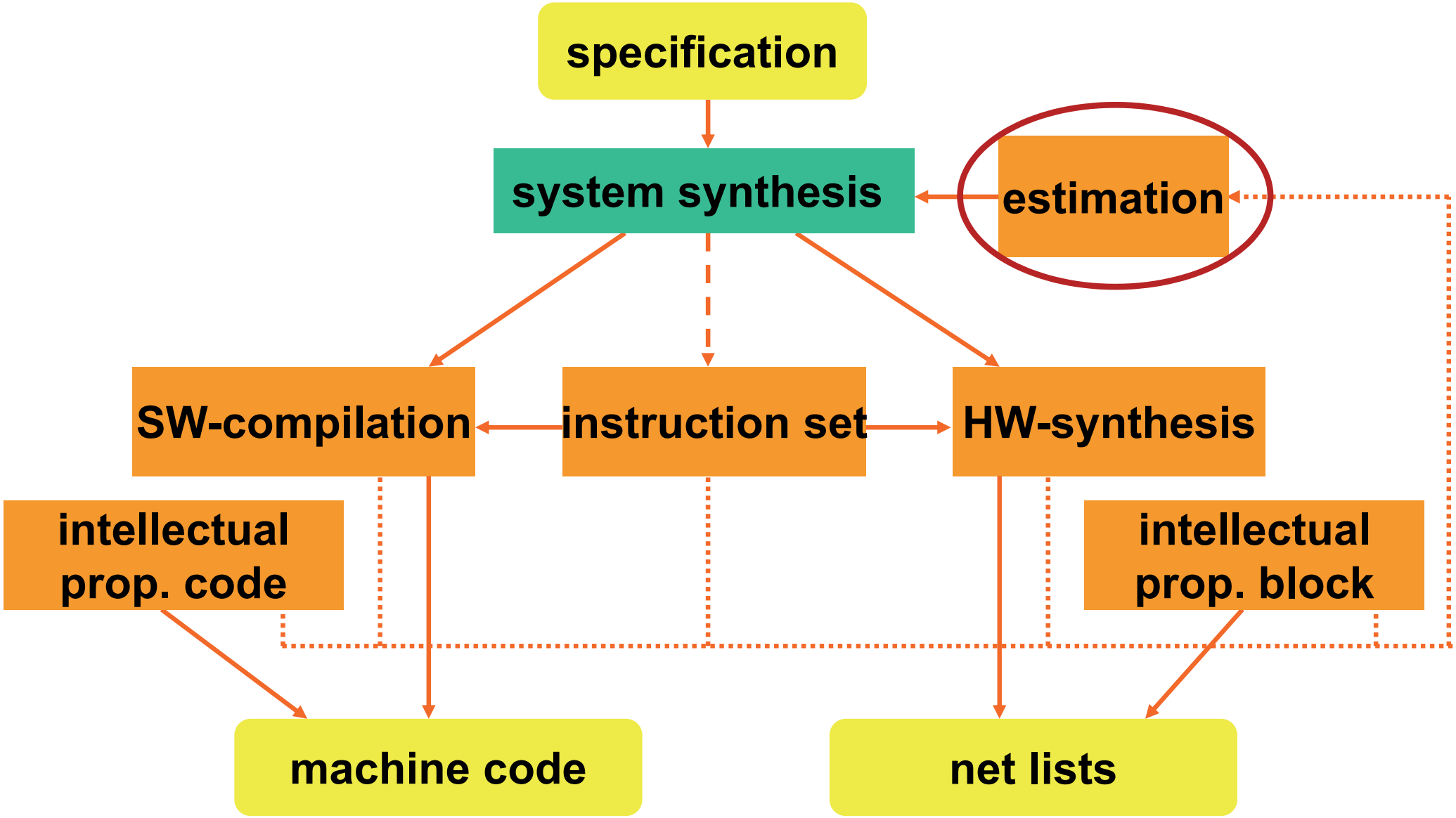
Hardware-Software Codesign

8. Performance Estimation

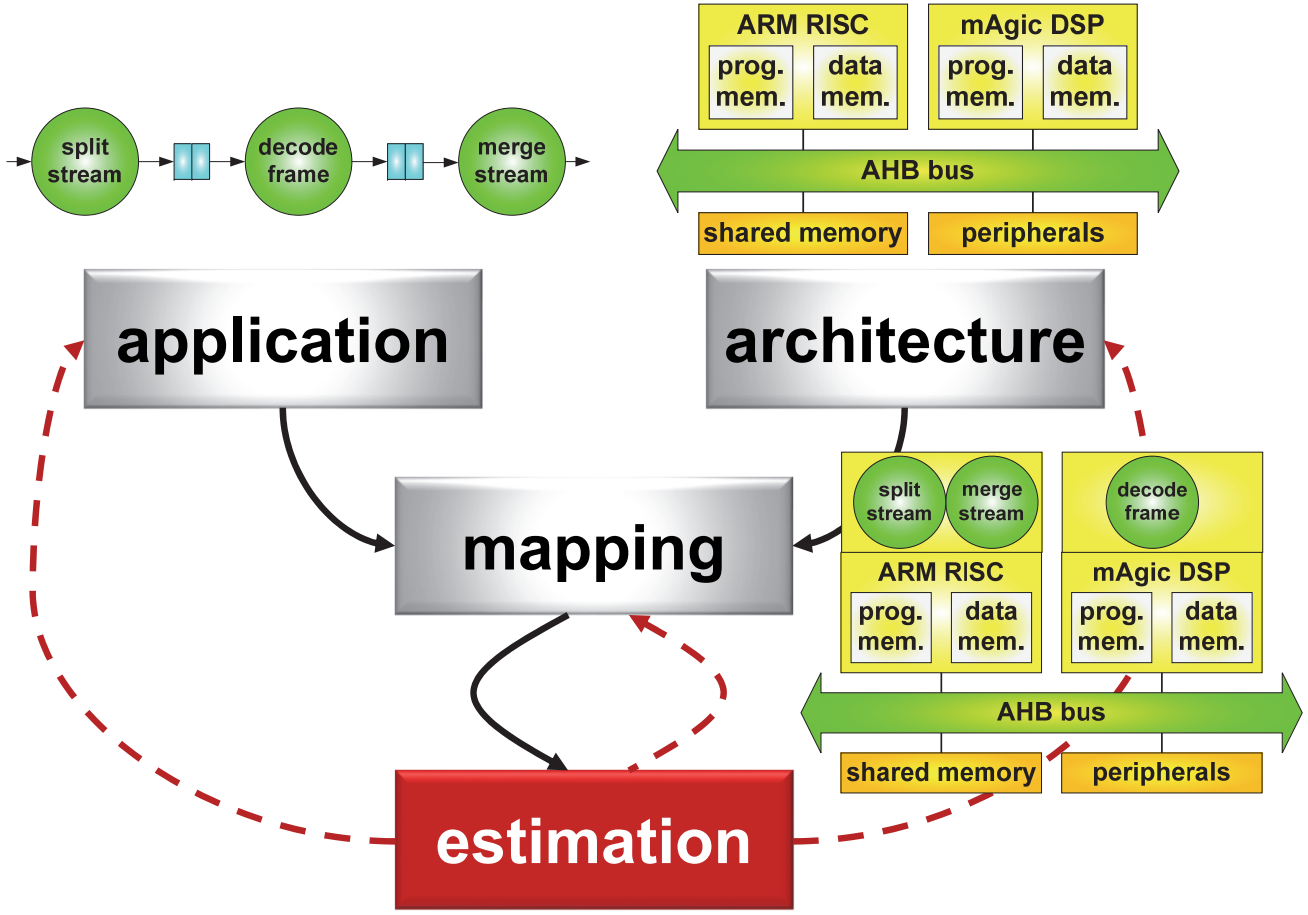
Lothar Thiele

System Design



Motivation

Objective function values that guide the design space exploration are obtained through **performance estimation.**

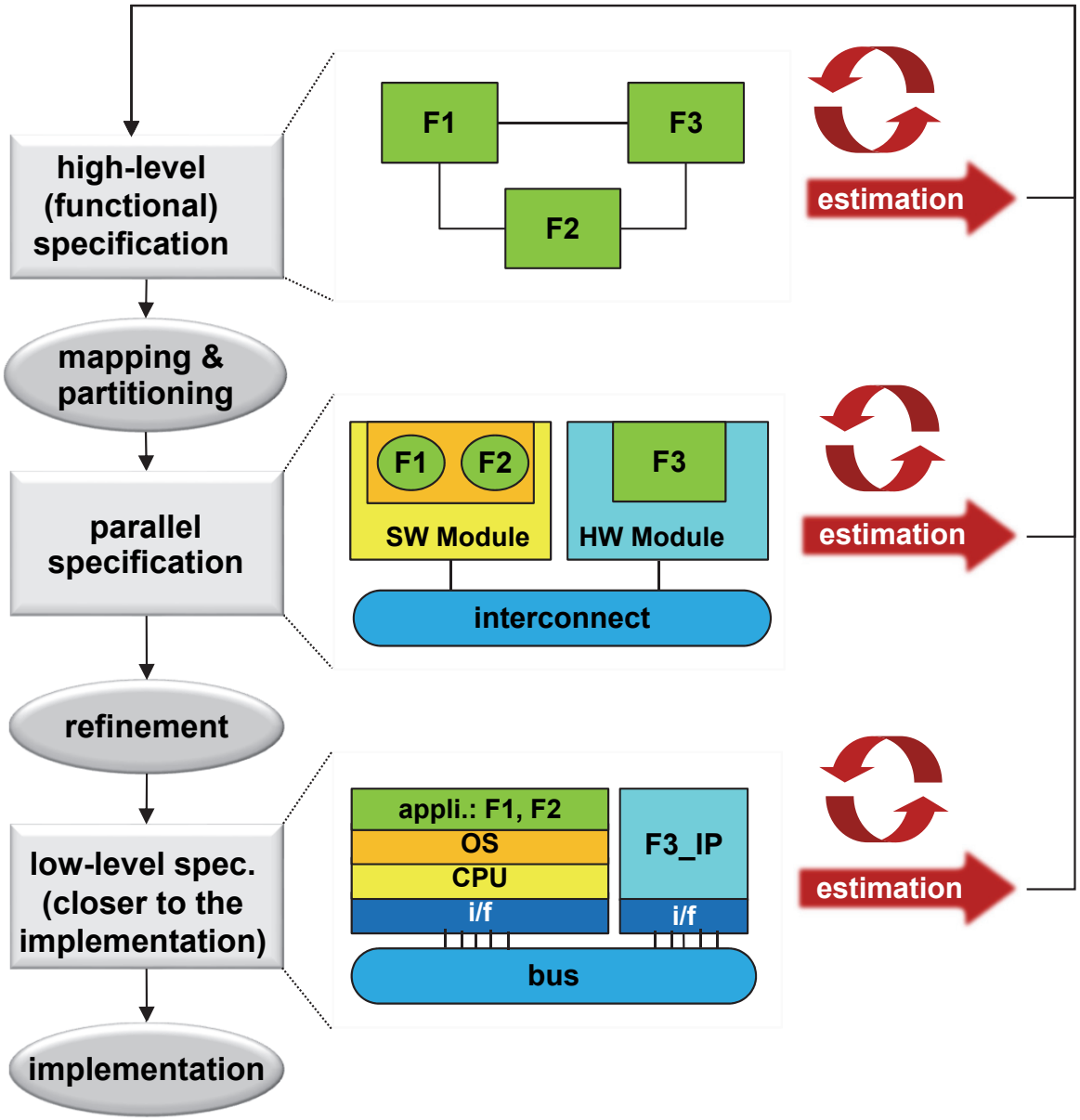


Design space exploration may change

- **application** (algorithms and/or parallelization)
- **architecture** (hardware)
- **mapping** (binding and scheduling)

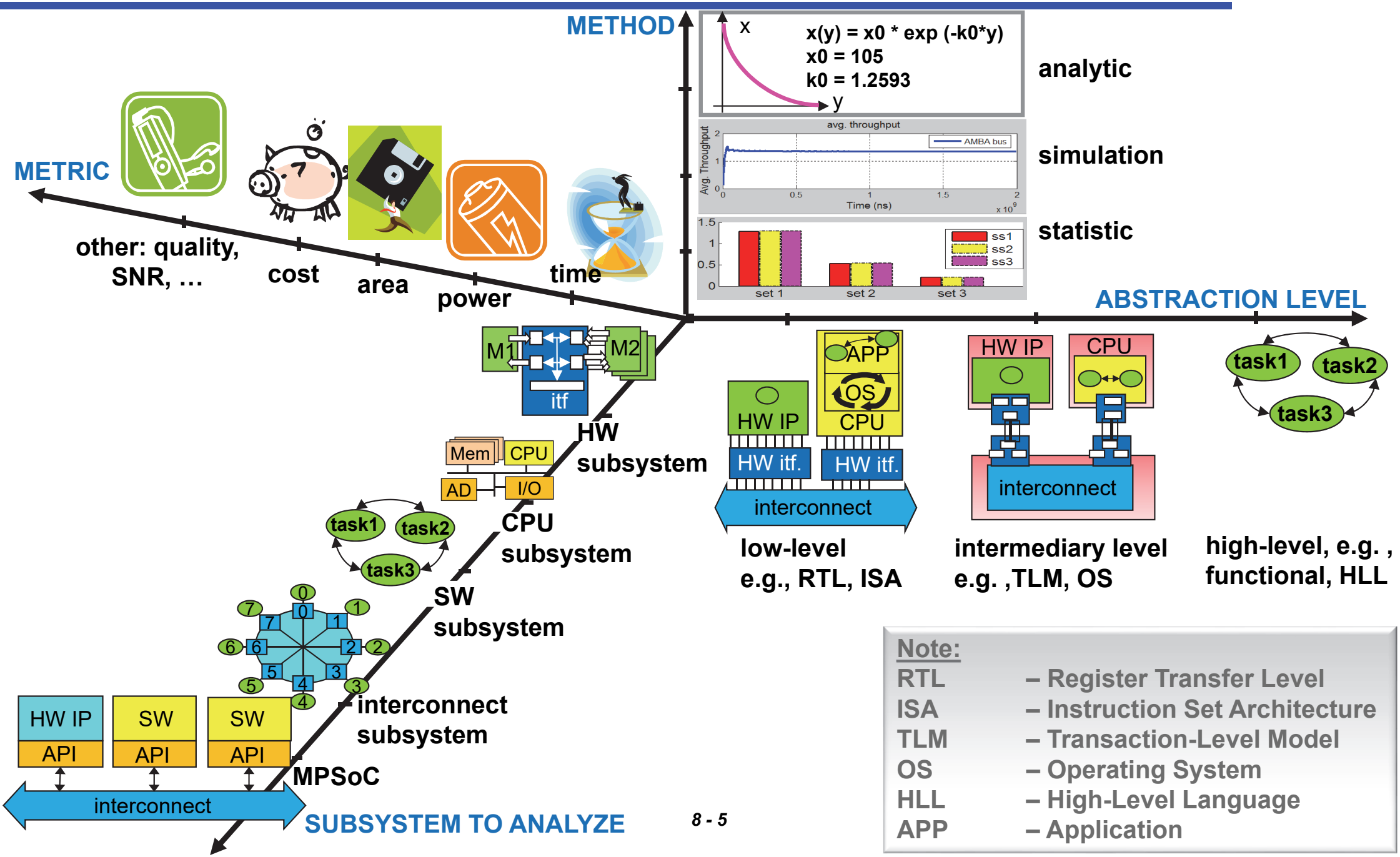
based on system (estimated) performance

Performance Estimation in Design Flow



- **high-level**
  - *advantages:* short estimation time, implementation details not necessary
  - *drawbacks:* limited accuracy, e.g. no info about timing
- **low-level**
  - *advantages:* higher accuracy
  - *drawbacks:* long estimation time, many implementation details need to be known

Performance Estimation – Global Picture



Note:

RTL	– Register Transfer Level
ISA	– Instruction Set Architecture
TLM	– Transaction-Level Model
OS	– Operating System
HLL	– High-Level Language
APP	– Application

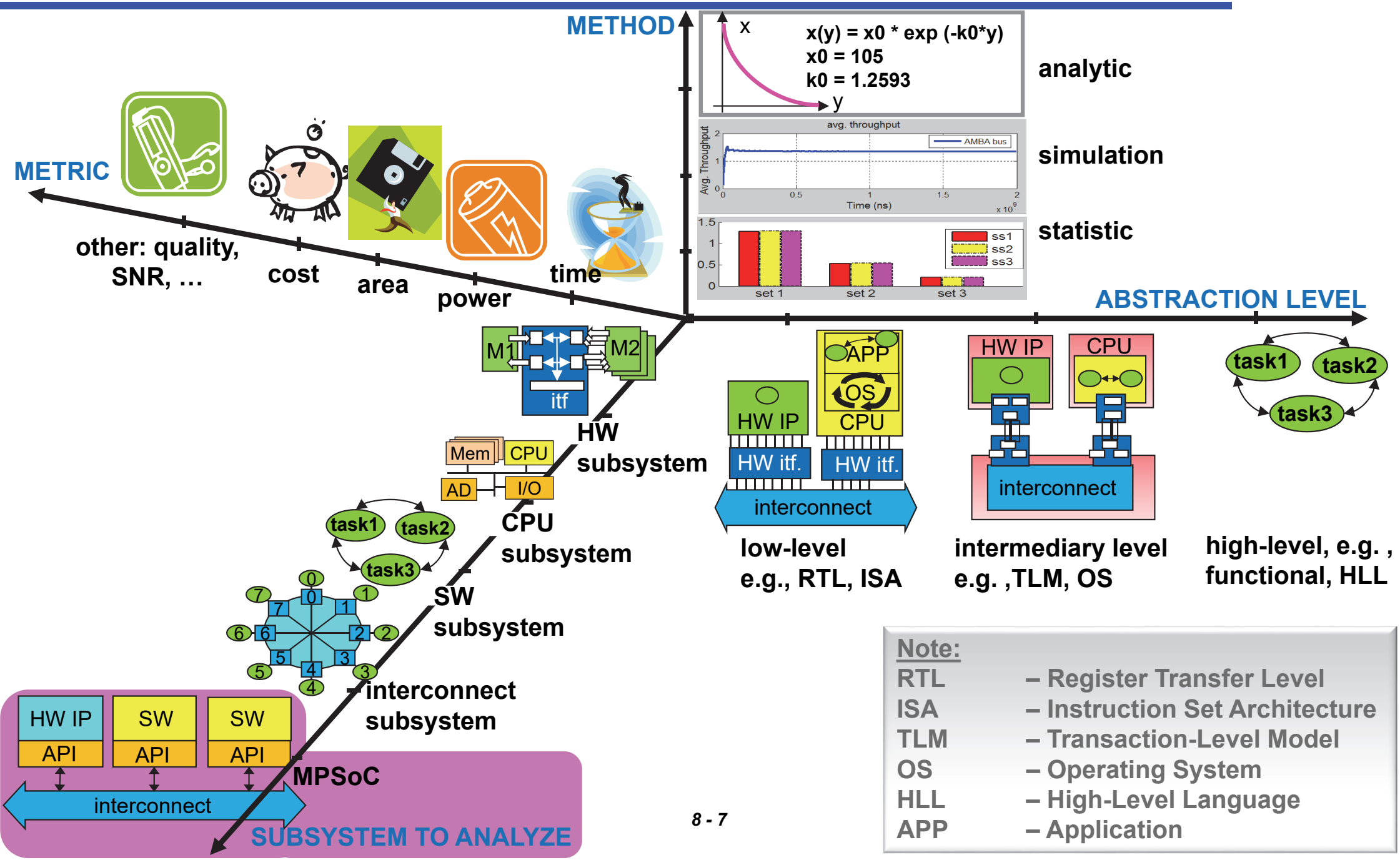
Why Do We Need Performance Estimation?

- **Validation of non-functional aspects**
  - equivalence between specification and implementation of non-functional properties (e.g., timing, power, energy, memory consumption)

- **Design space exploration**

  (guiding design decisions and optimization)
  - part of the feedback cycle (see global flow)

Performance Estimation – Global Picture



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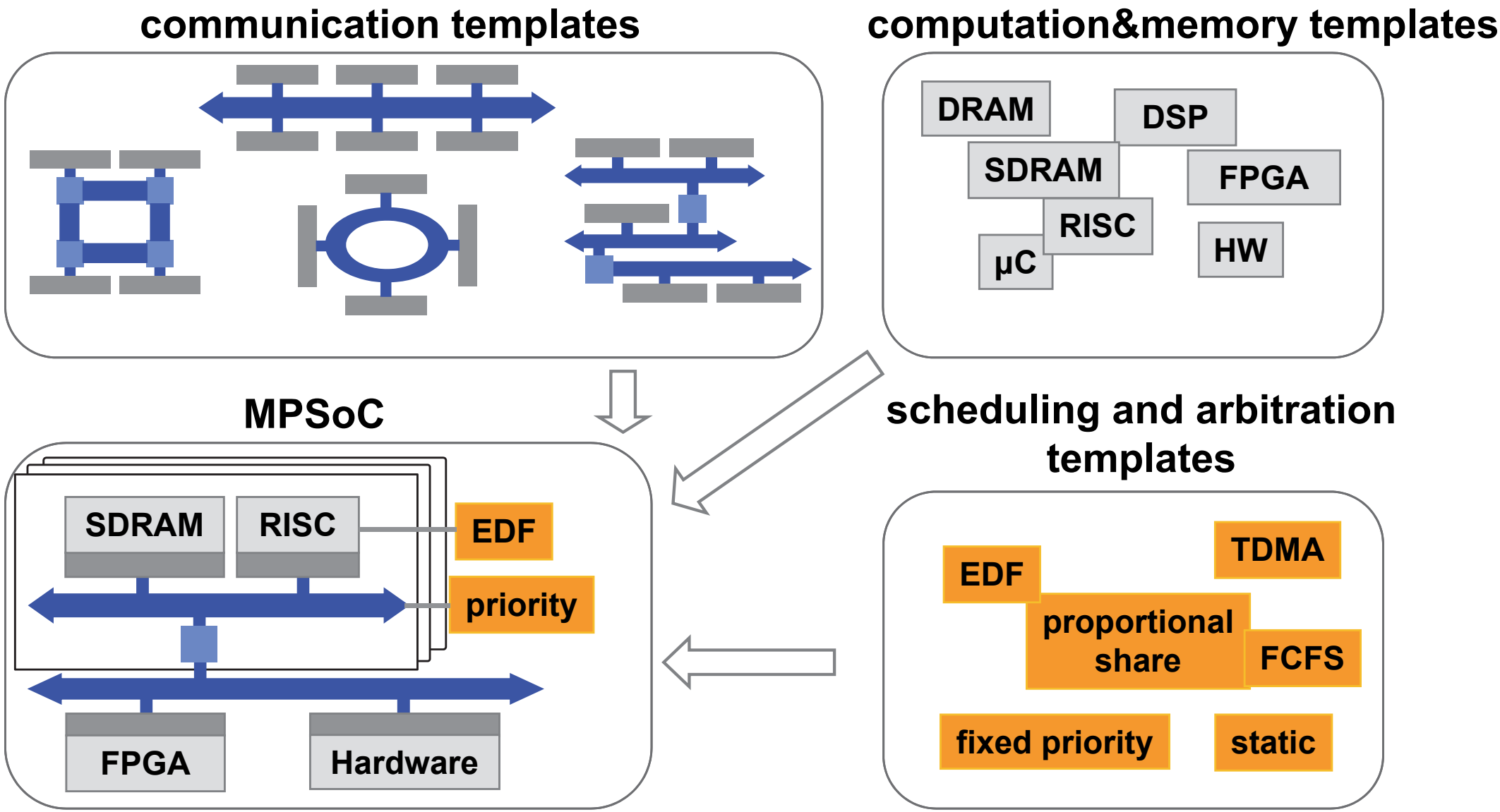
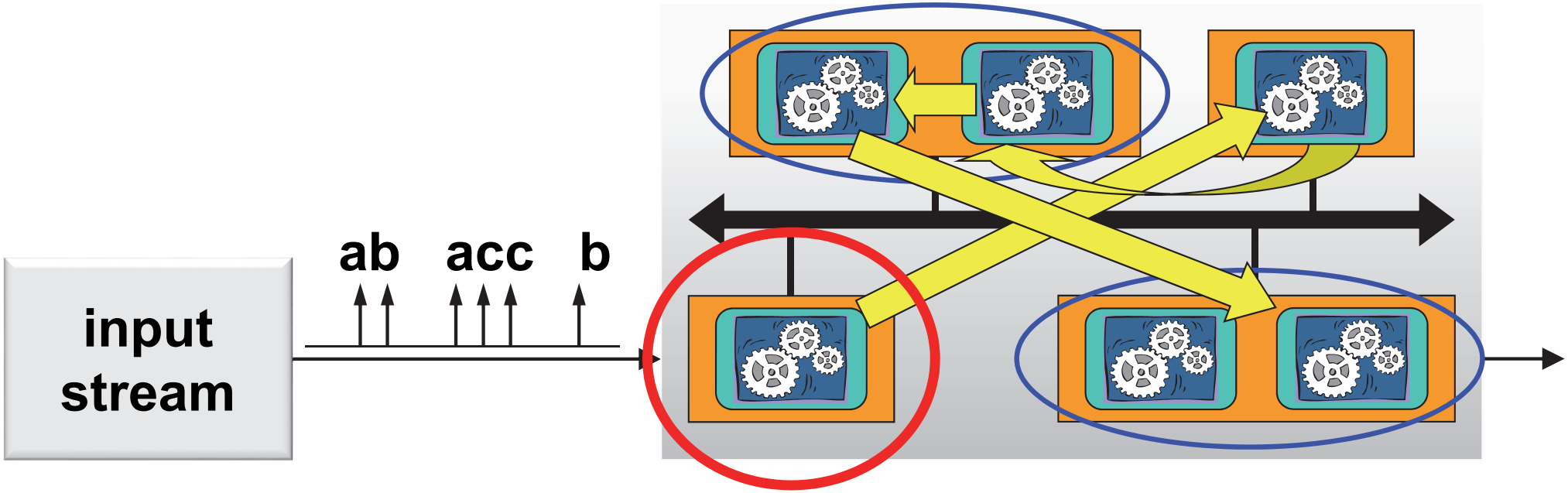
Multi-Processor System-on-Chip



Why is MPSoC Performance Estimation Difficult?

- **Computation, communication, and memory**
  - (non-deterministic) computation in processing nodes
  - (non-deterministic) communication delays
  - (non-deterministic) memory accesses
  - complex resource interaction via scheduling/arbitration
- **Cyclic timing dependencies**
  - internal data streams interact on computation and communication resources
  - interaction determines stream characteristics
- **Uncertain environment**
  - different load scenarios
  - unknown (worst case) inputs

Illustration of Evaluation Difficulties



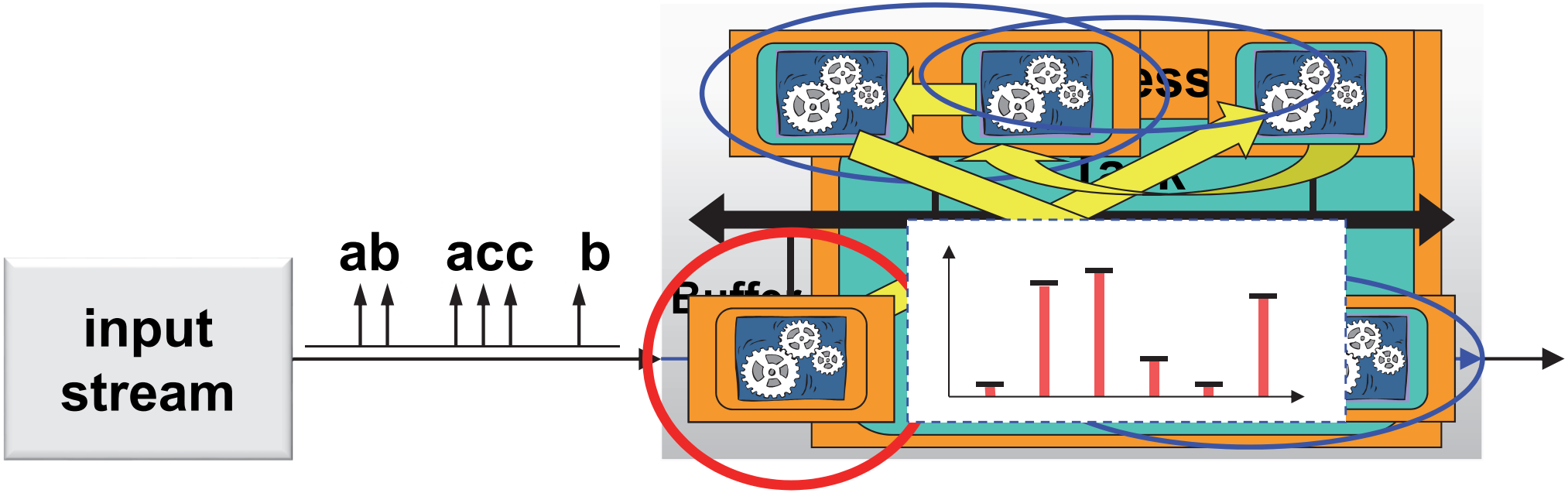
task communication

task scheduling

complex input:

- timing (jitter, bursts, ...)
- different event types

Illustration of Evaluation Difficulties



task communication

task scheduling

complex input:

- timing (jitter, bursts, ...)
- different event types

variable resource availability

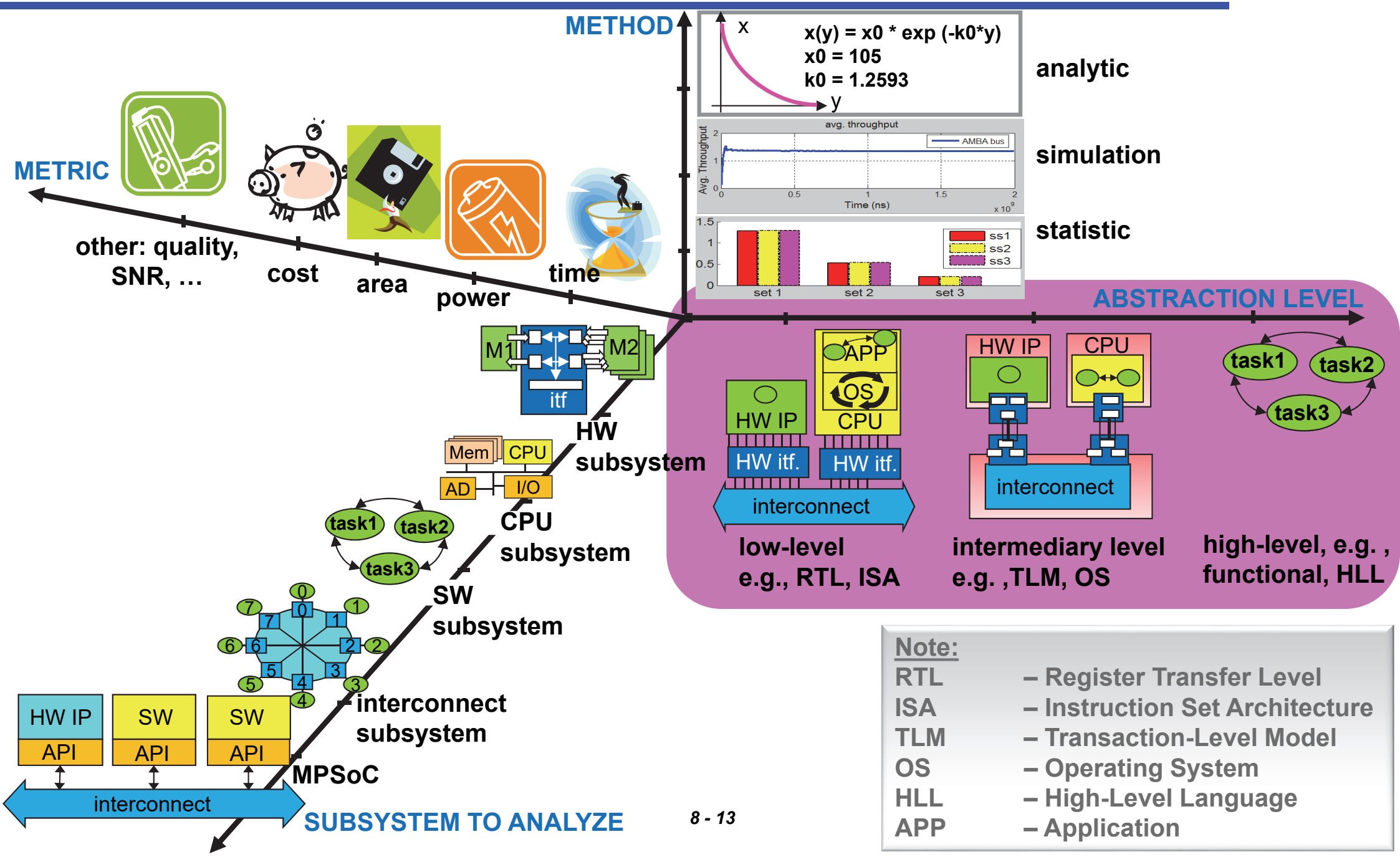
variable execution demand

- input (different event types)
- internal state (program, cache, ...)

Performance Estimation Requirements

- Estimation should be **composable** in terms of
  - ***subsystems*** and their ***interactions***, i.e., HW, SW, interconnect
  - ***computation***, ***communication***, ***memory***, ***scheduling***
- Estimation should cover different **metrics**
  - e.g., delay, throughput, memory consumption, power, energy, temperature, cost, …
- Estimation should represent a **reasonable trade-off** between
  - (1) effort in terms of computation time
  - (2) accuracy of performance estimates
  - (3) set-up time / modeling effort

Performance Estimation – Global Picture



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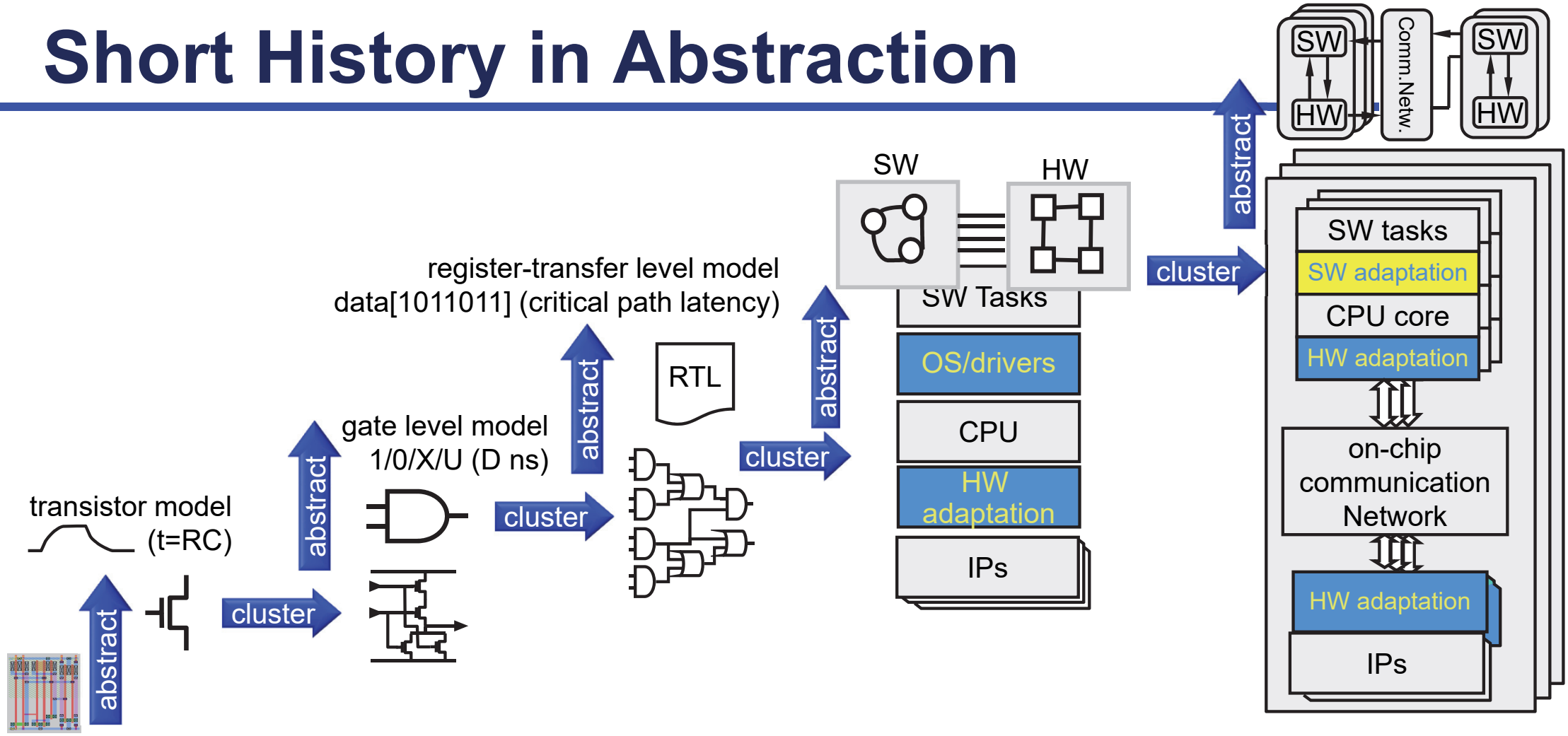
Short History in Abstraction



1970's | 1980's | 1990's | 2000's | 2010+

technology: transistors, layouts

signal: gate, schematic, RTL

transaction: SW, HW systems

tokens: SW tasks, comm. backbones, IPs

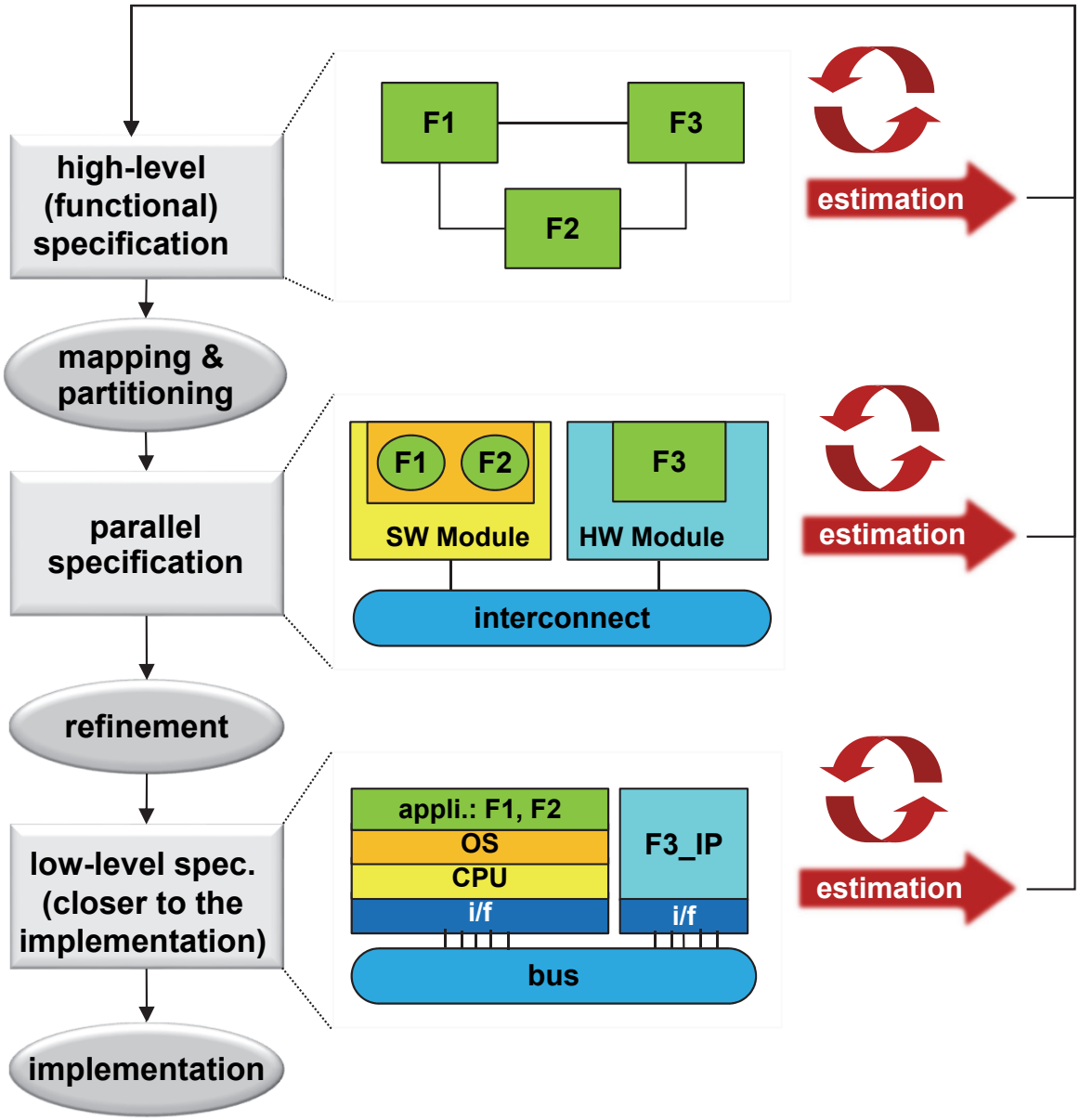
simulator: SPICE

simulator: VHDL

simulator: SystemC /ISS

simulator: HW/SW codes./cosim. tools; formal methods

Performance Estimation in Design Flow



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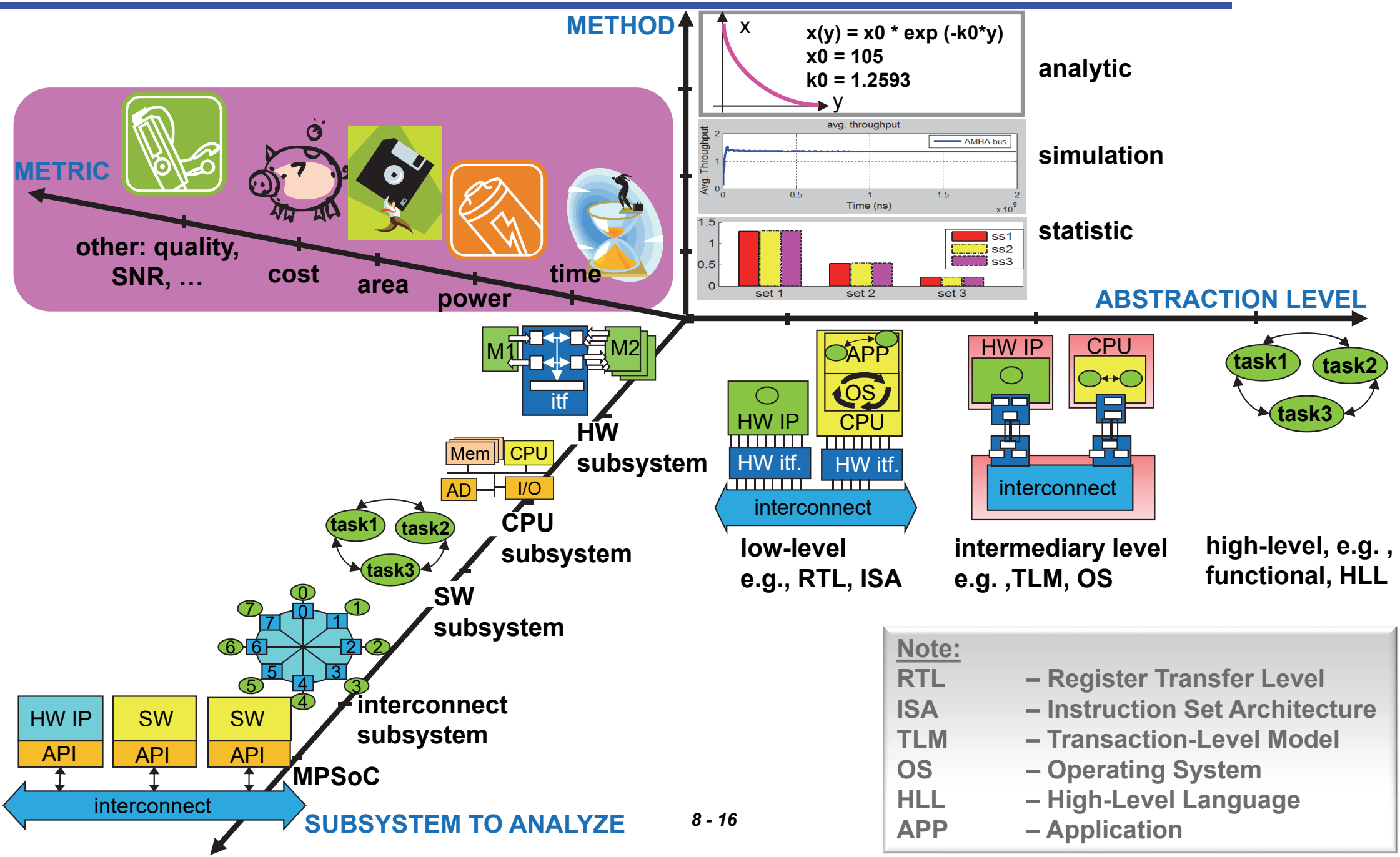

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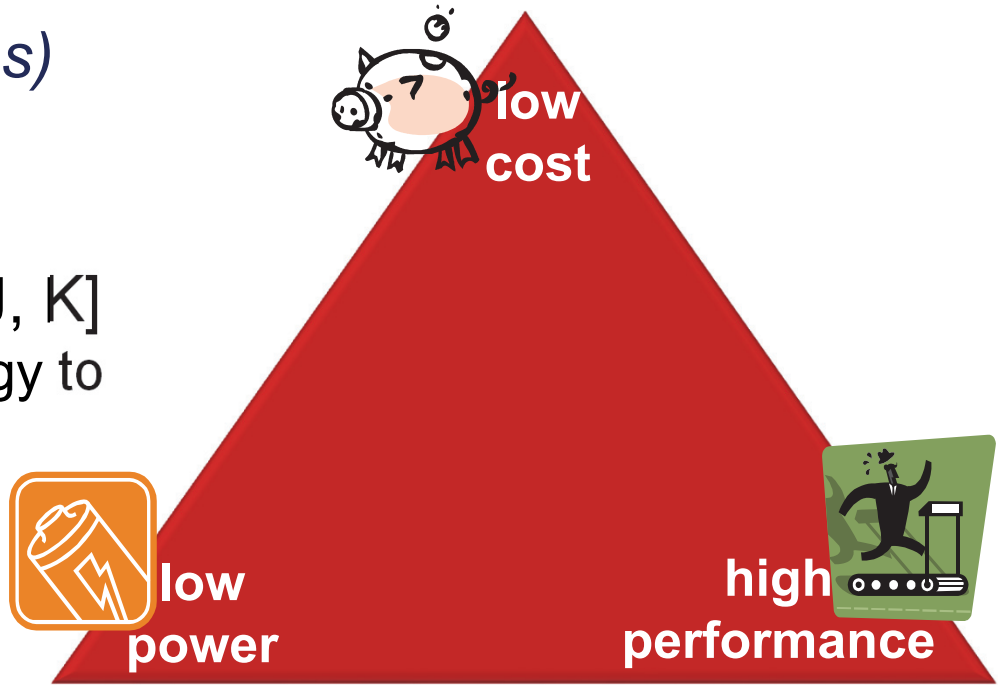
Performance Metrics

Performance metric = function defined on relevant non-functional properties of a system, which gives a quantitative indication on system execution

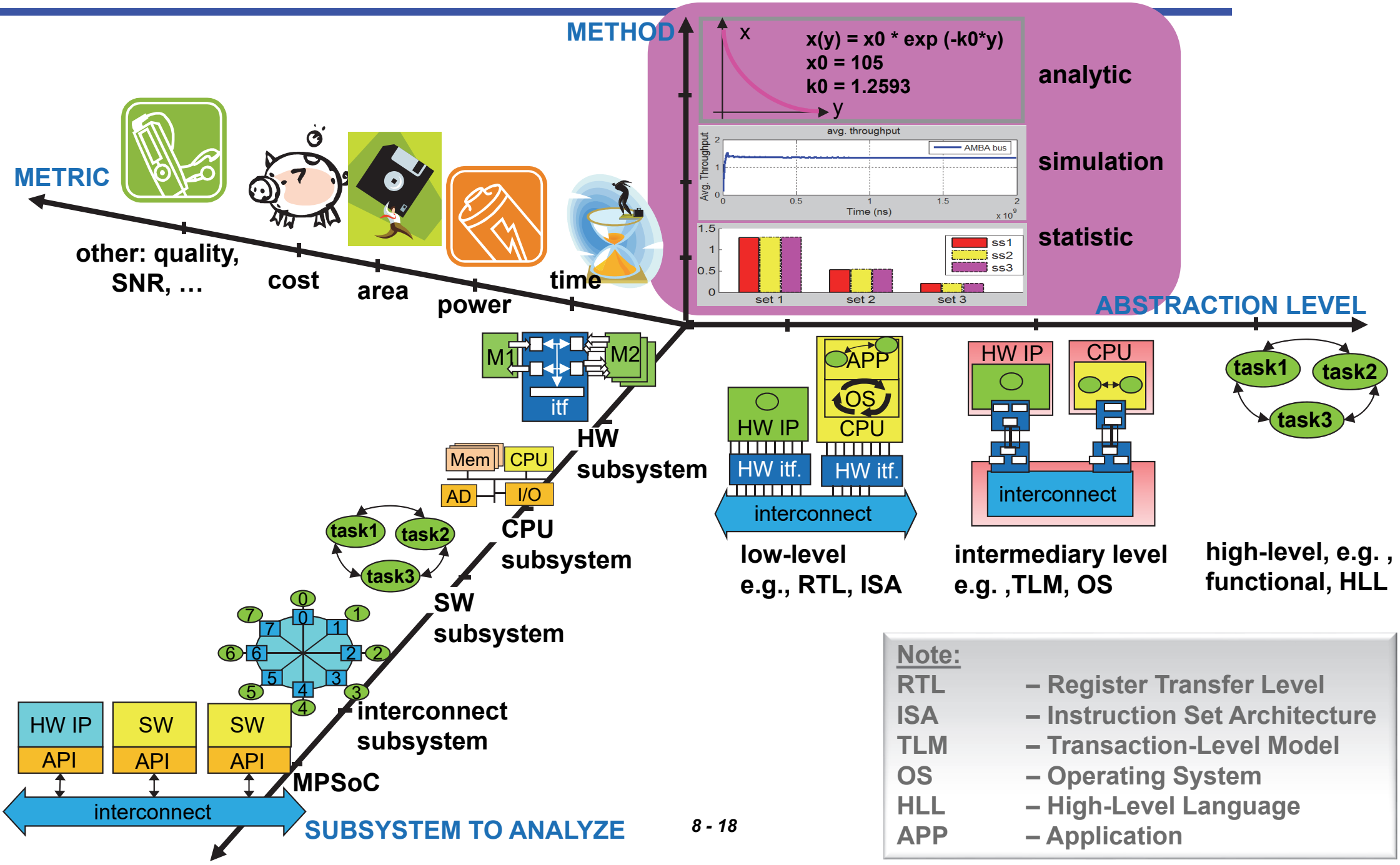
Examples (relevant for embedded systems)

- **time** [seconds]
  e.g., end-to-end delay, throughput, latency
- **power, energy, temperature** [mW, mJ, K]
  e.g., power consumed by the network, energy to execute a task, maximal temperature
- **area** [mm^2]
  e.g., area of an integrated circuit
- **cost** [$]
  e.g., cost of parts, labor, development cost
- ***other metrics***
  e.g., SNR (signal to noise ratio) - video/sound quality



generally, performance metrics are conflicting!

Performance Estimation – Global Picture



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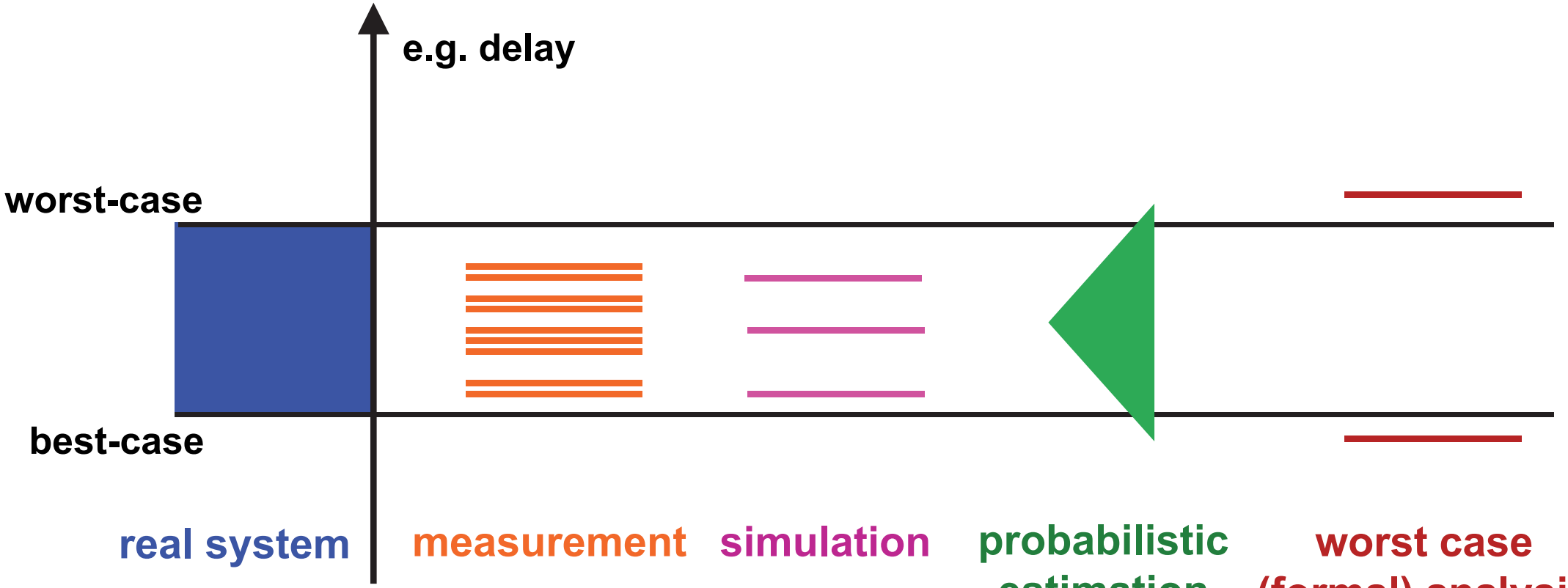
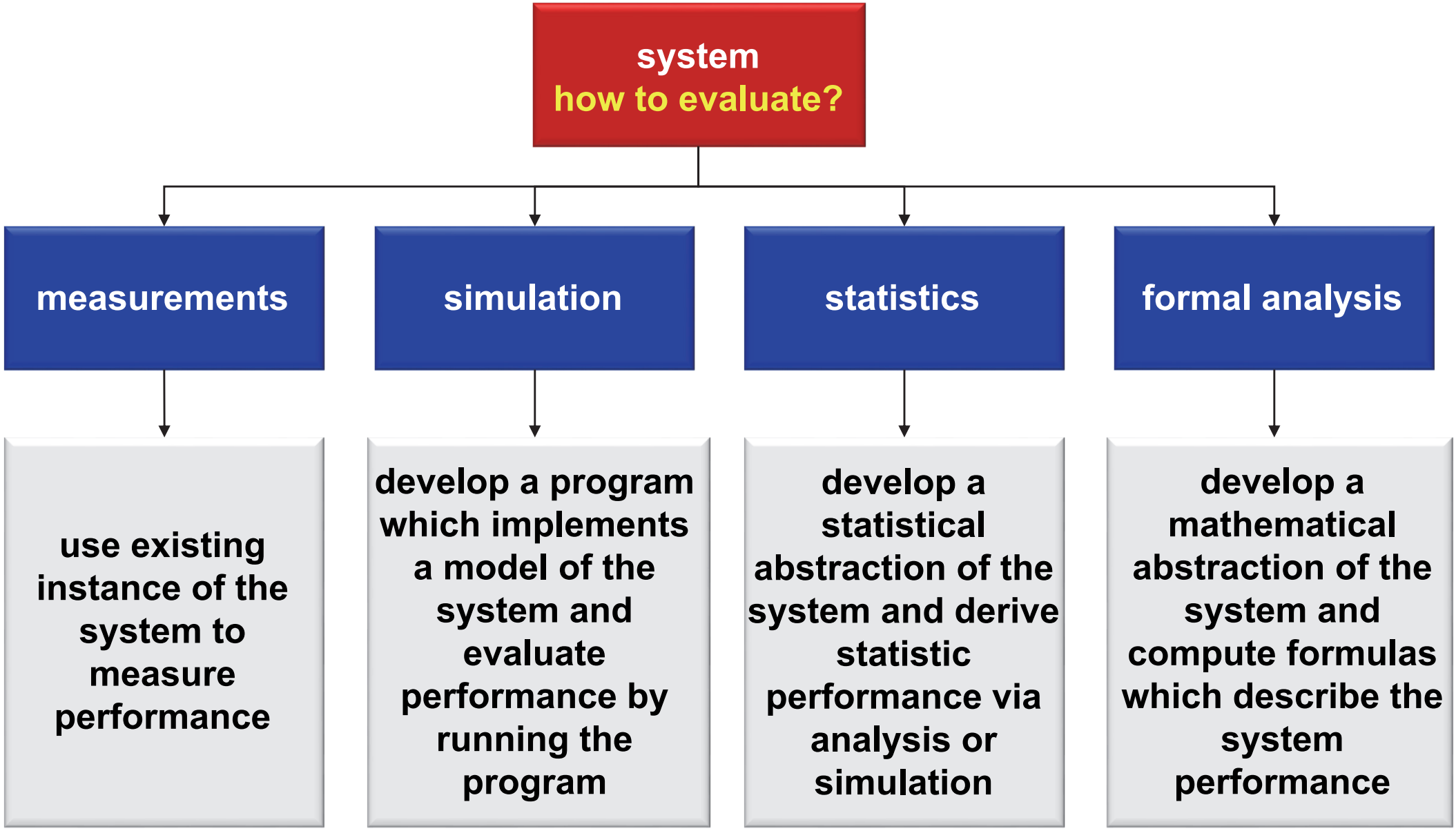
Performance Estimation Methods – Illustration



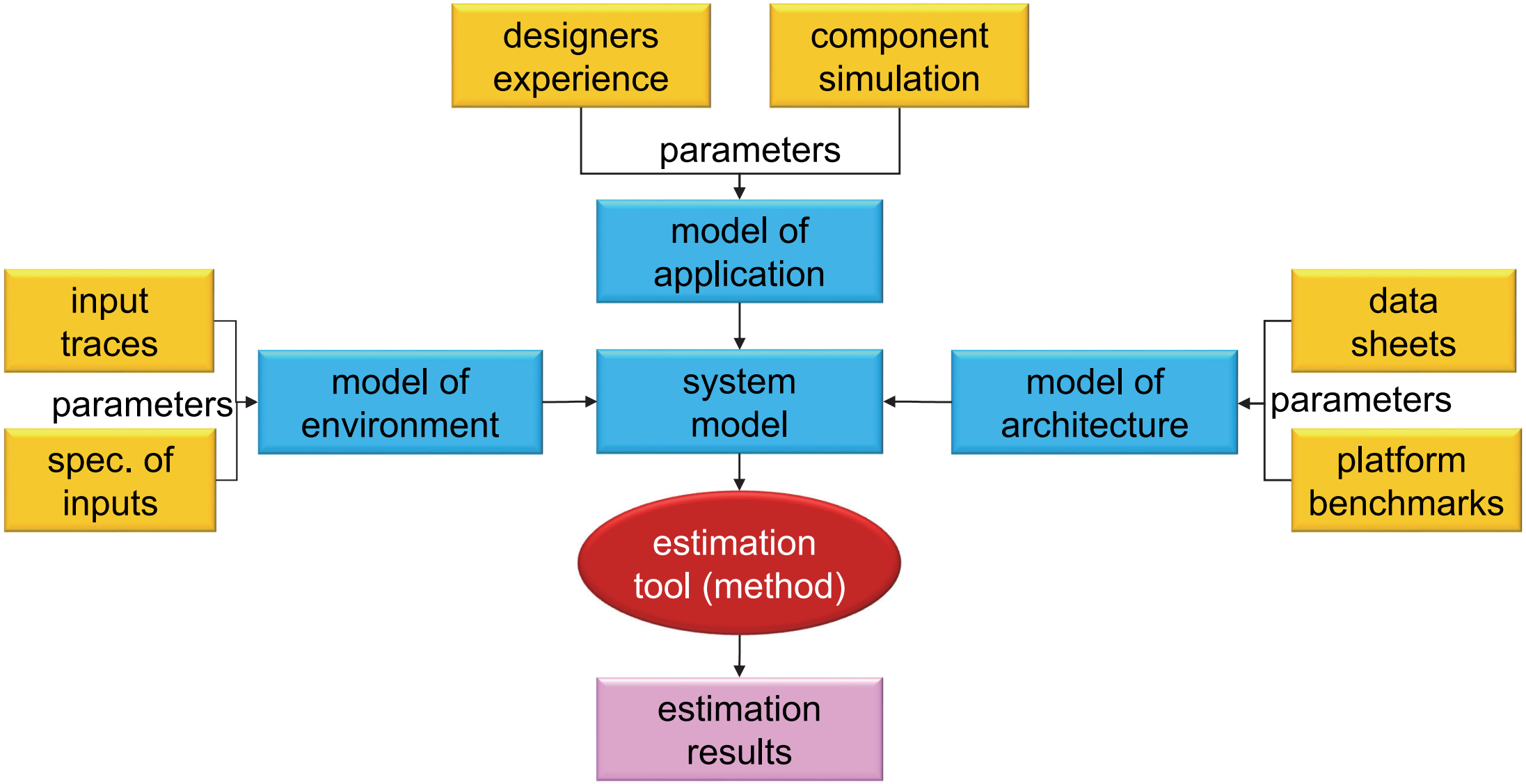
→ *lecture 6*

→ *lectures 9-10*

Performance Estimation Methods – Description



System Compositional Performance Estimation



1.Static Analytic Models

- Describe computing, communication, and memory resources by *algebraic equations*
- Describe system properties by *parameters*, e.g., data rate
- Combine relations

$$comm\_delay = \left\lceil \frac{\#words(M1, M2)}{burst\_size} \right\rceil comm\_time$$

+ fast and simple estimation

- generally inaccurate modeling

(e.g., resource sharing not modeled)

2. Dynamic Analytic Models

- Combination between
  - **static models** possibly extended by non-determinism in run-time and event processing
  - **dynamic models** for describing, e.g., resource sharing mechanisms (scheduling and arbitration)

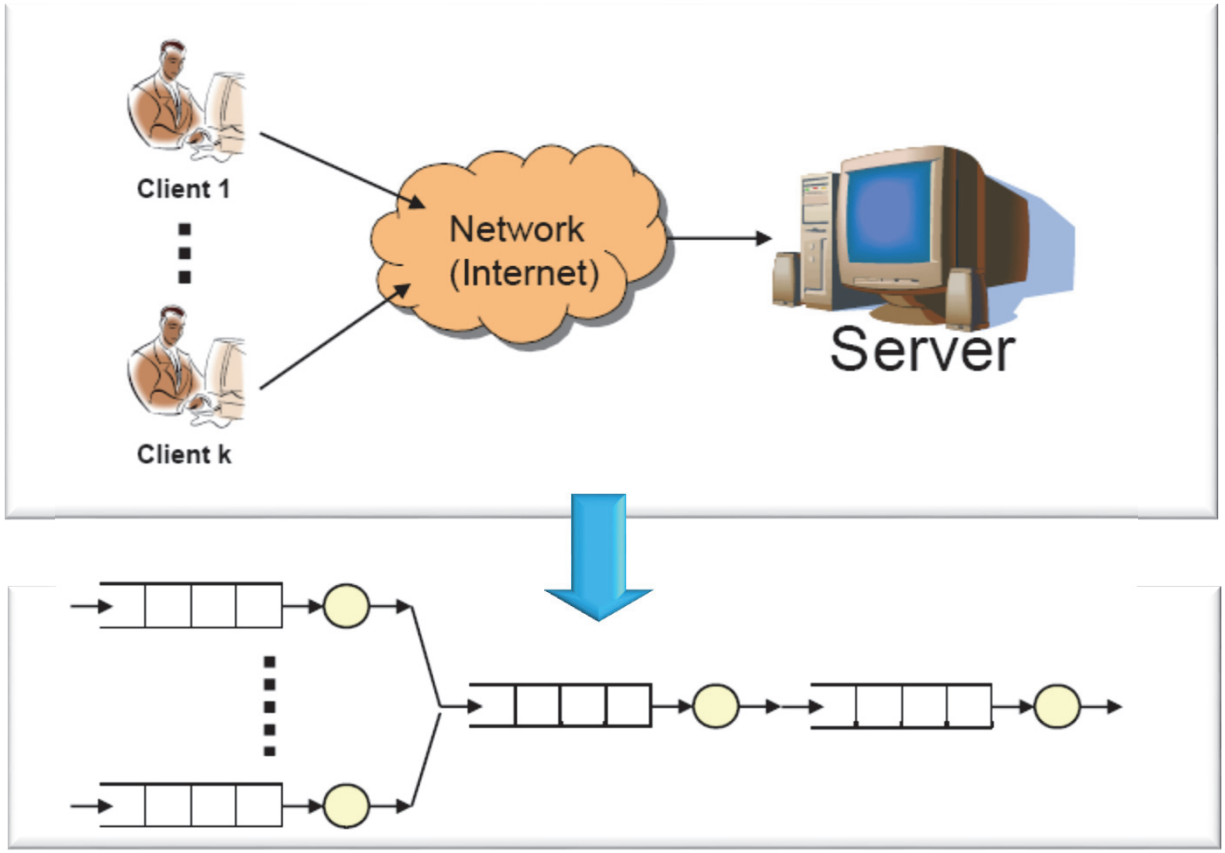
- Existing approaches
  - ***classical real-time scheduling theory***
  - ***stochastic queuing theory***

    (statistical bounds) – example 1
  - ***analytic (non-deterministic) queuing theory***

    (worst case/best case bounds) – example 2

Example – Queuing Systems

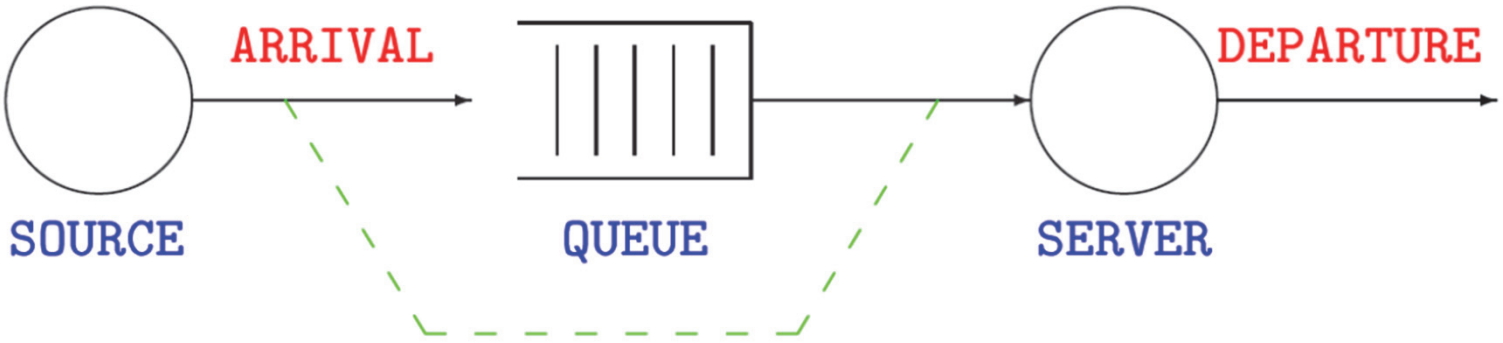
- ***Example:*** clients request some service from a server over a network
- **Analysis goals:**
  - performance of the server
  - performance of the network



Ex. 1 – Stochastic Queuing Systems

- A ***stochastic model*** of queuing systems is described by probability density functions (distributions) of
  - arrival rates
  - service mechanisms
  - queuing disciplines
- ***Performance measures*** are stochastic values (functions)
  - average delay in queue
  - time-average number of customers in queue
  - proportion of time server is busy

classical M/M/1 queuing system:
(M = Markovian (exponential) distribution)

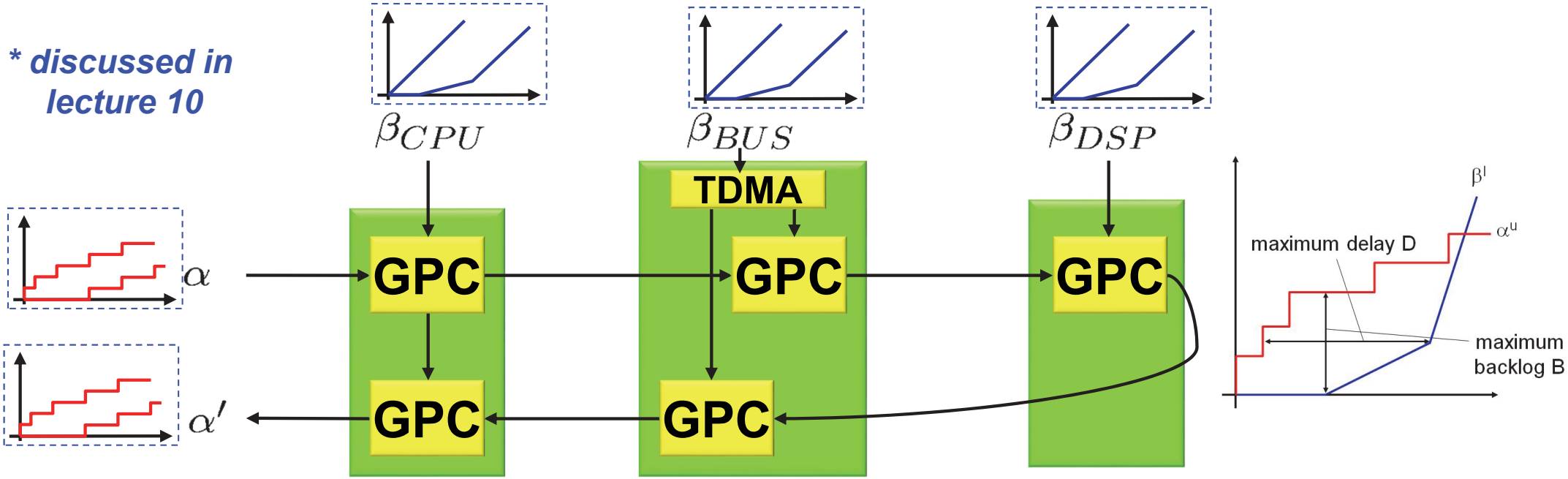


Ex. 2 – Worst-Case/Best-Case Queuing Systems

- A ***worst/best-case queuing system*** is described by worst/best-case bounds on system properties
  - w/b-case bounds on arrival times
  - w/b-case bounds on server behavior
  - resource interaction

- ***Performance measures***
  - worst/best-case delay in queue
  - worst/best-case number of customers in queue
  - worst/best-case system delay

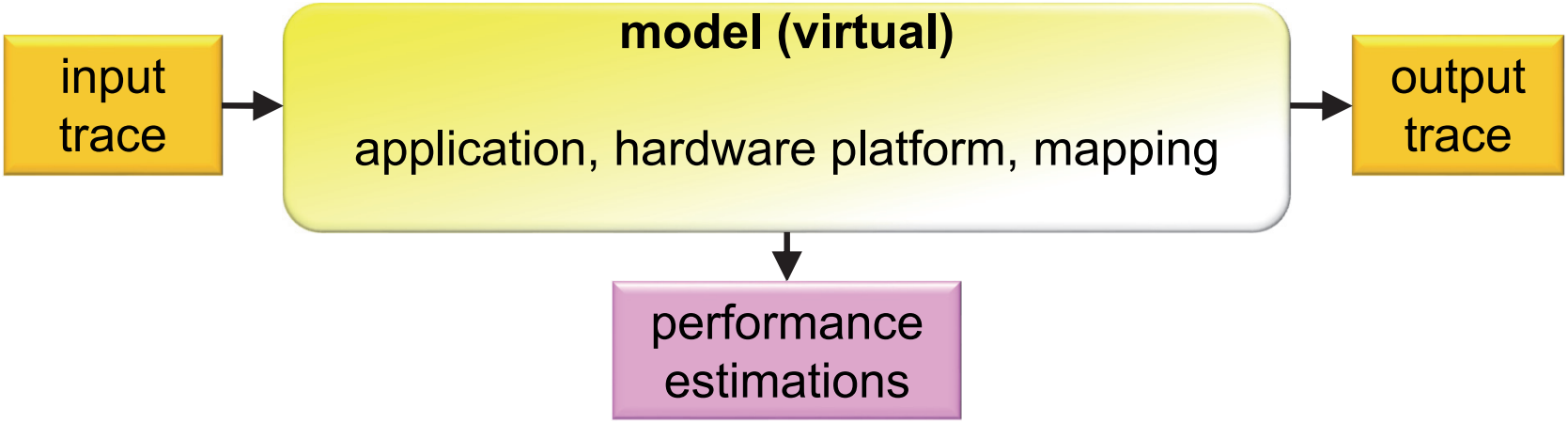
**** discussed in lecture 10***



3. Simulation

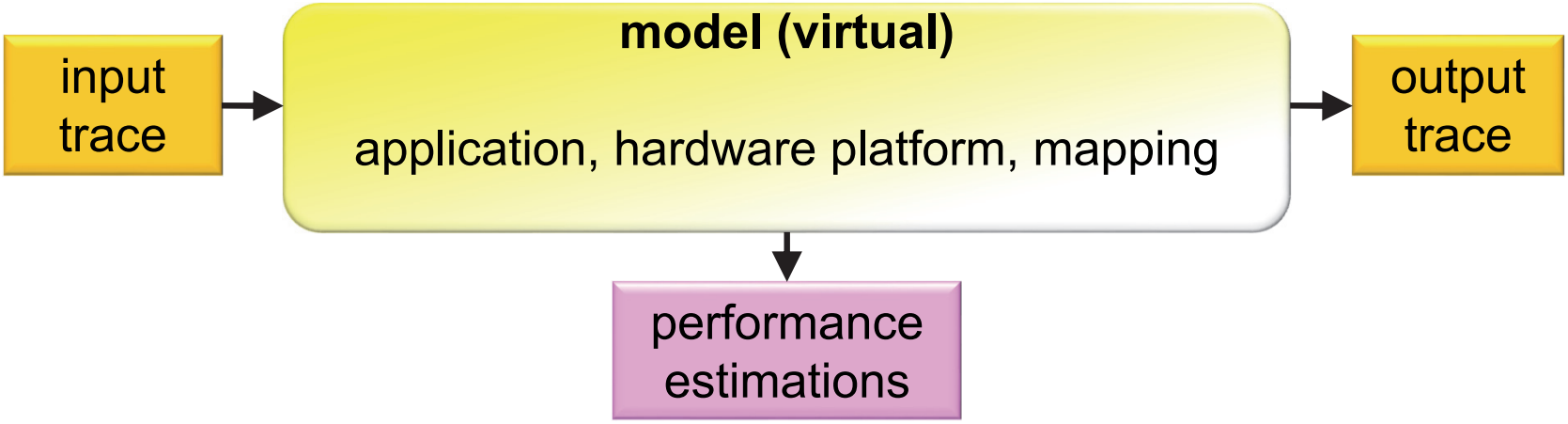
** discussed in lecture 6*

- **Model:**
  - program implementing a model of the system (application, hardware platform, and mapping)
  - performance is evaluated by running the program



3. Simulation (contn.)

- **Simulation**
  - considers hardware platform and mapping of application onto that platform (by means of a virtual platform)
  - combines functional simulation and performance data
  - evaluates behavior for one simulation scenario (i.e., specific input trace and initial system state)



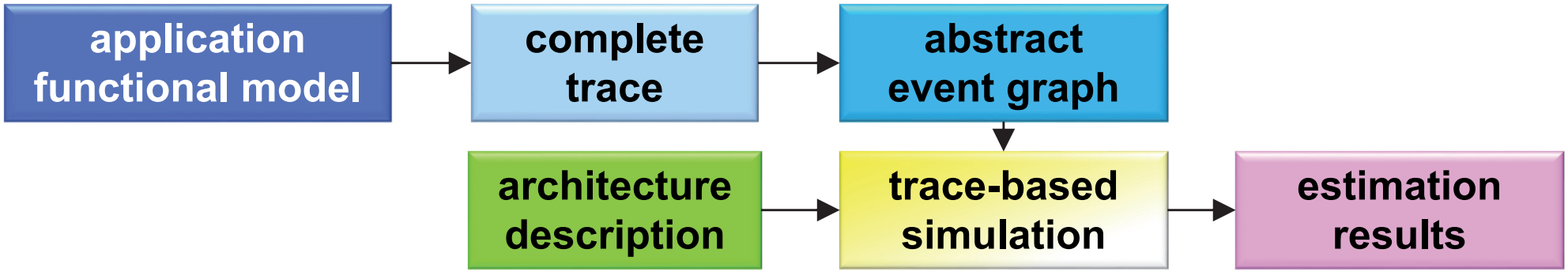
- **Advantages/disadvantages**

- (typically) complex set-up and extensive runtimes

+ ... but accurate results and good debugging possibilities

Ex. 3: Trace-Based Simulation

- ***Trace-based simulation:*** abstract system-level simulation (without timing)
  - faster than low-level simulation
  - … but still based on a single input trace
- **Abstraction**
  - **application:** *abstract execution traces*
    → graph of events: **`read`**, **`write`**, and **`execute`**
  - **architecture:** *"virtual machines"* and *"virtual channels"*
    → calibrated with non-functional properties (timing, power, energy)



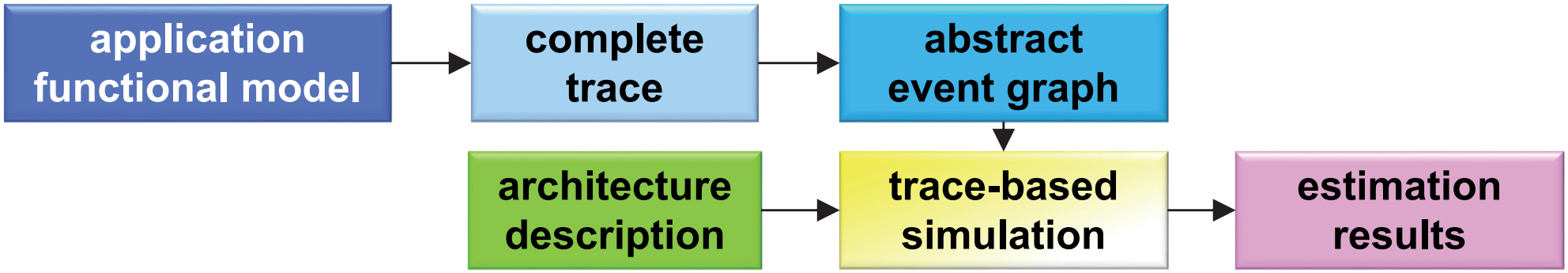
e.g. [Lahiri et al., 2001], [Pimentel et al., 2006], [Huang et al., 2009]

Ex. 3: Trace-Based Simulation

- Trace-based simulation steps
  - **build application abstract model**

    → execution trace determined by functional application simulation
  - **extend abstract model with architecture and mapping**

    → event graph extended by non-functional properties of virtual architecture elements
  - **simulation of extended model**



e.g. [Lahiri et al., 2001], [Pimentel et al., 2006], [Huang et al., 2009]

What is ahead?

- ***Section 6: Simulation (already done…)***
  - Simulation-based approaches to system estimation.
- ***Section 9: Worst Case Execution Time Analysis***
  - Analytic method to bound the execution time of tasks.
- ***Section 10: Modular Performance Analysis***
  - Analytic method to bound properties of distributed hardware-software systems.
- ***Section 11: Thermal-aware Design***
  - Simulation-based and analytic methods for temperature estimation