Adaptive Runtime Resource Management of Heterogeneous Resources

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Carreer Overview

Studies: Licentiaat Informatica (VUB, 1991-1995)

1995	2001	2004	07	08
Doctoral Researcher VUB	Postdoc University of Bern, Switzerland	Chargé de cours ULB	Principal Scientist imec	
				Professor (10%) KUL

Juggling Hats

IMEC
- Embedded devices
- Runtime resource management

ULB
- Object versioning
- AOP

KUL
Language Design

imec

- Research organization located in Leuven
  - world-leading independent research center in nanoelectronics and nanotechnology
  - More Moore research targets semiconductor scaling for the 22nm technology node and beyond.
  - More than Moore research invents technology for nomadic embedded systems, wireless autonomous transducer solutions, biomedical electronics, photovoltaics, organic electronics and GaN power electronics.
- Numbers
  - Budget: ± 200 M€
  - Staff: ± 1700
  - Cleanroom: ± 10,000 m2

The ARES Team


Maja
D'Hondt


Rogier
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Carolina
Blanch


Paul
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IMEC Ph.D. Students


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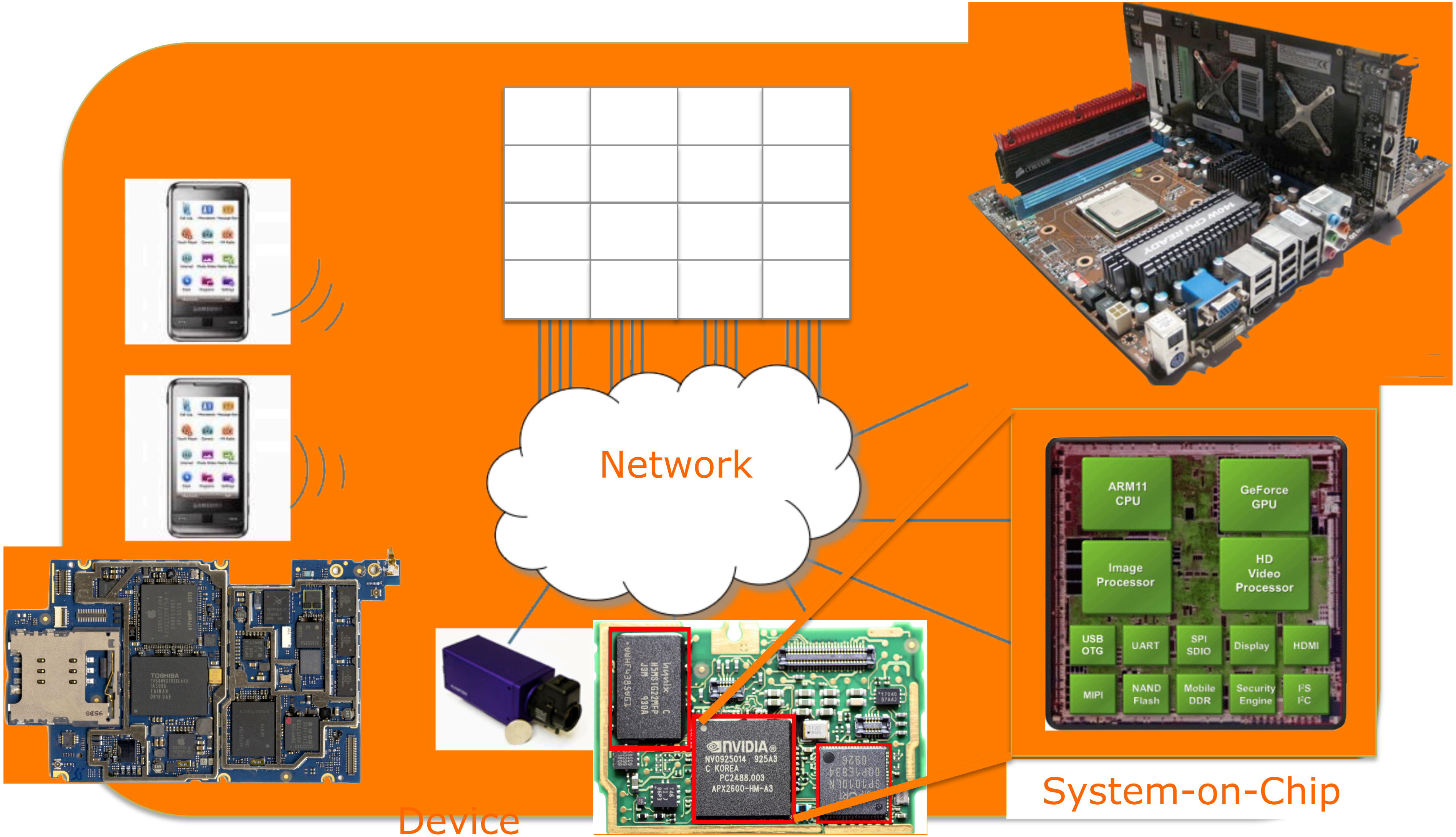
Master Students

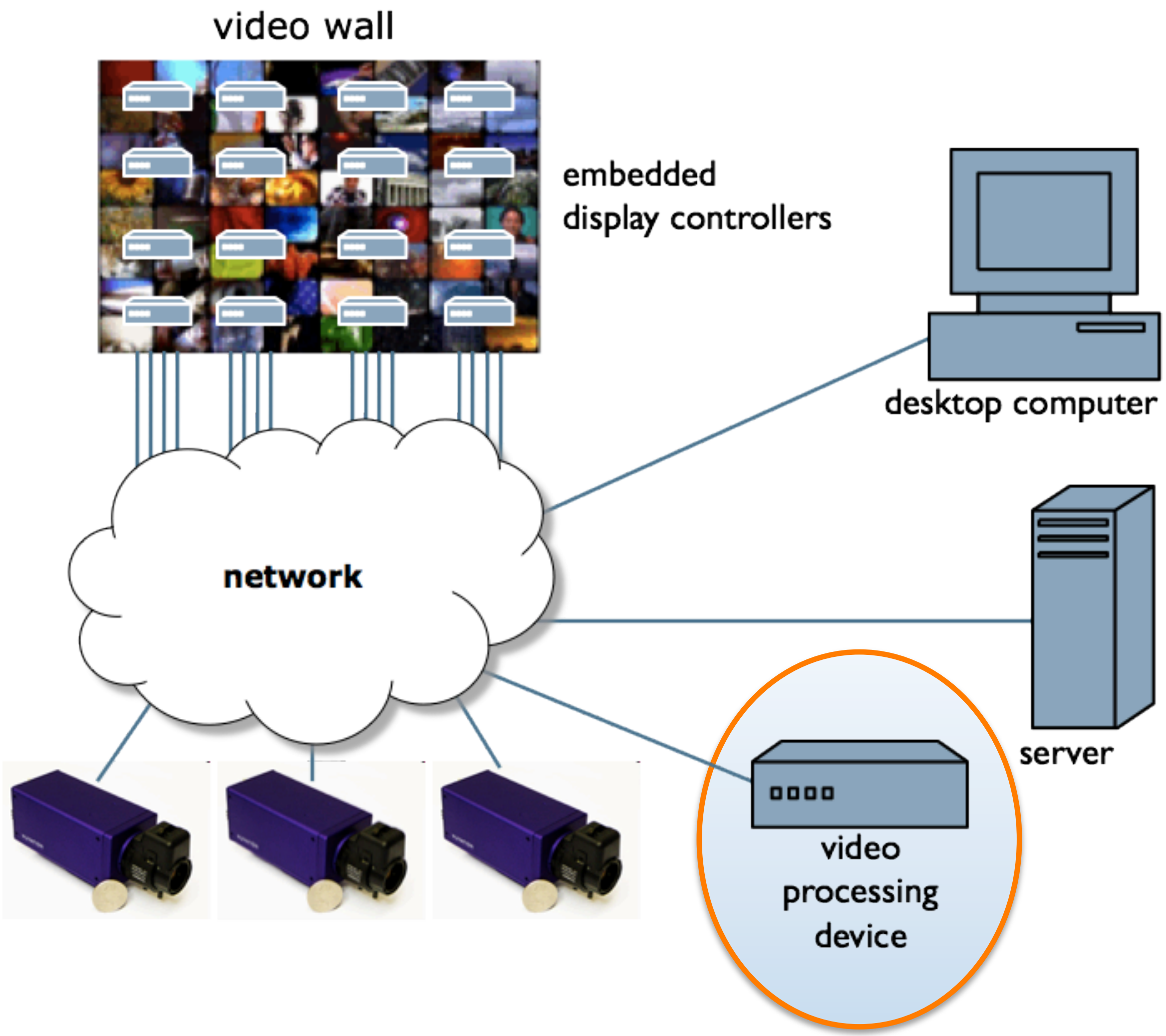

Tipnis
Ameya

ARES General Goal

- Software that takes advantage of heterogeneous platforms is becoming the rule.
- Developing such software is hard because:
  - A decision needs to be made regarding what software components can use what resources,
  - that decision varies at runtime as the application's context changes.
  - moreover the decision needs to result in good performance,
  - And the software needs to run with many possible resource configurations
- ARES solves this problem through adaptive runtime resource management, a solution that monitors applications at runtime and decides the assignment of resources to software components at runtime according to a decision algorithm.

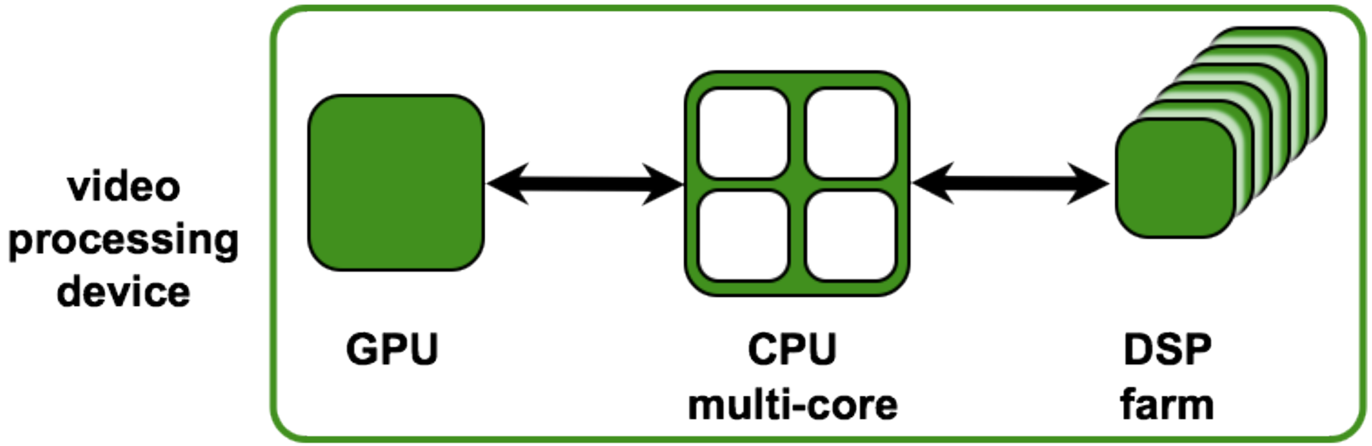

Network
ARM11 CPU
GeForce GPU
Image Processor
HD Video Processor
USB OTG
UART
SPI SDIO
Display
HDMI
MIPI
NAND Flash
Mobile DDR
Security Engine
System-on-Chip
Device

Context: Networked Video Processing



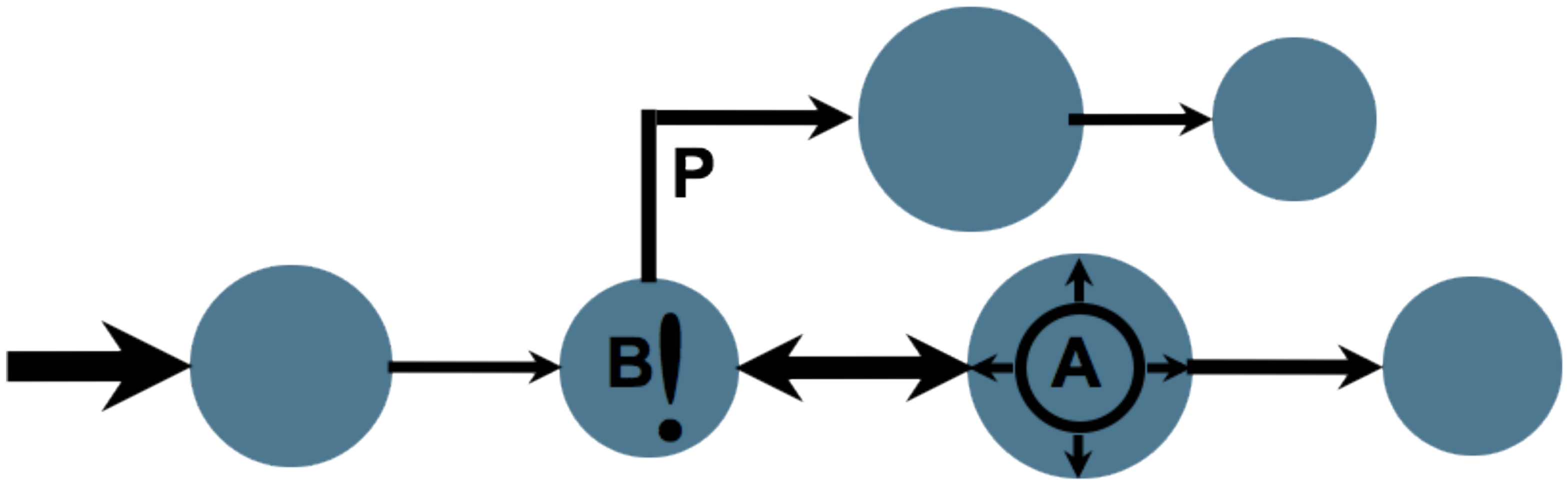
Video Processing Device

- Previously: custom hardware
- Now: Device with off-the-shelf CPU and GPU and optionally DSP-board
  - Many different kinds of CPUs and GPUs -> high variability
  - hardware evolves rapidly -> high variability



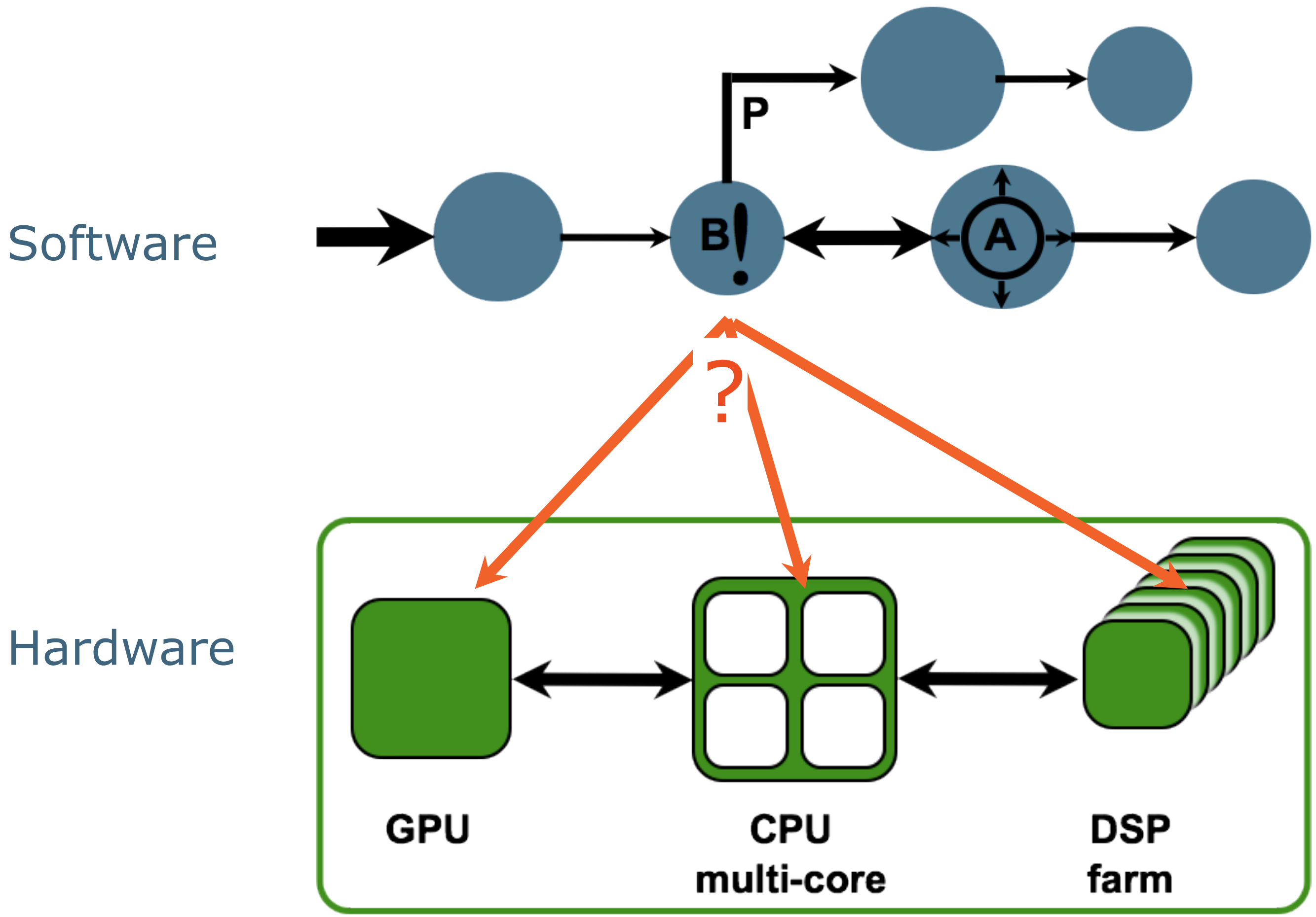
Software Pipelines in Video Processing

- Software to process and analyze video streams
  - encoders, decoders, transcoders, object (e.g. logo) detection, video scalers, color space conversion, ...
- Characteristics
  - Data-dependent: changing workloads (component A in example)
  - User/context interaction: changing pipelines (B triggers pipeline P)



Developing on Heterogeneous Platforms

- Assignment Problem: what runs where when?



Related Work

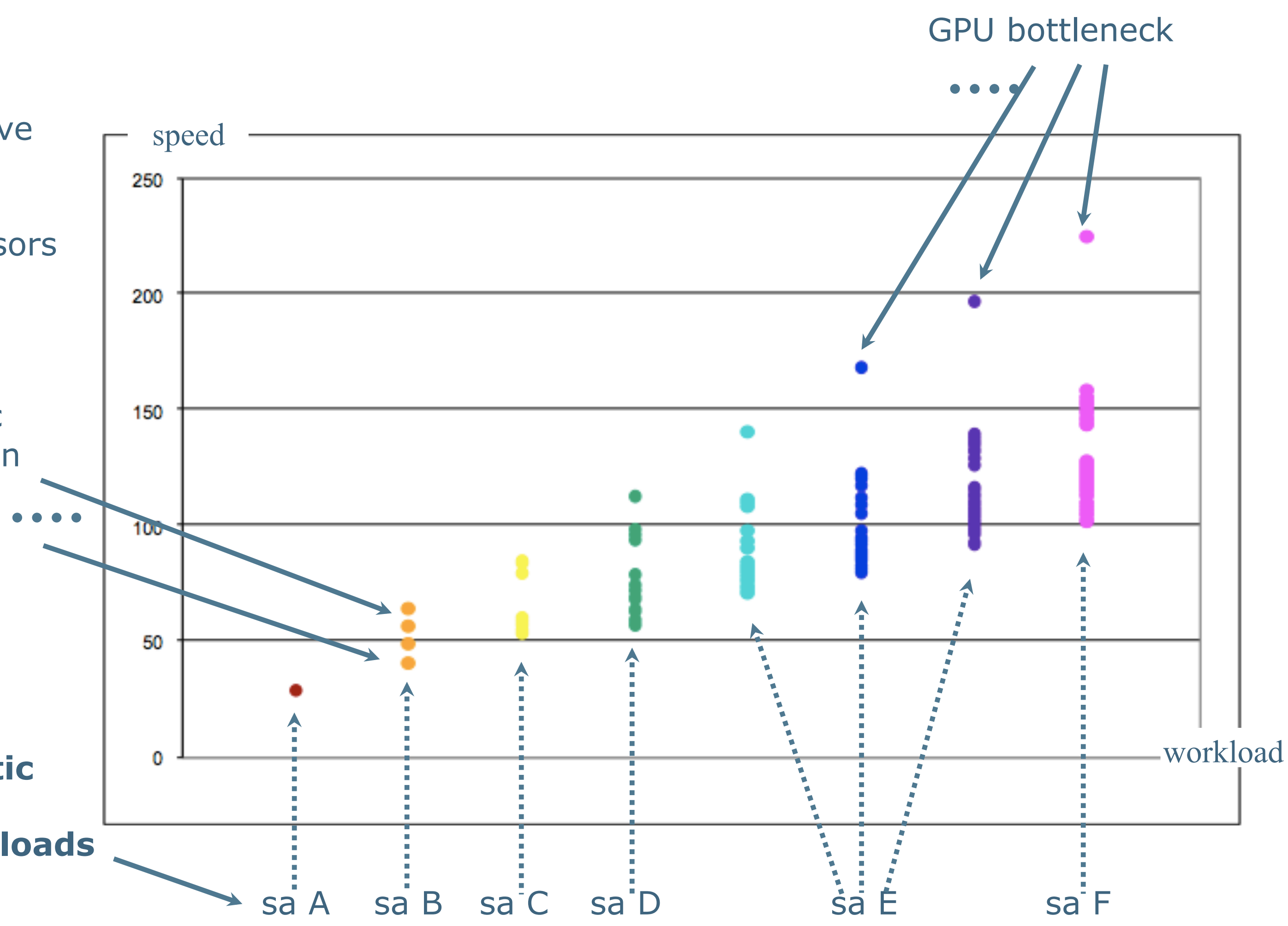
- Practice: (manual) design-space exploration + assumptions

- Task assignment for heterogeneous systems
  - V. J. Jiménez, L. Vilanova, I. Gelado, M. Gil, G. Fursin, and N. Navarro. *Predictive runtime code scheduling for heterogeneous architectures* [HiPEAC '09]
  - Finer-granularity imposing only simple assignment strategies
- Task scheduling on heterogeneous multicore architectures
  - C. Augonnet, S. Thibault, R. Namyst, and P.-A. Wacrenier. *StarPU: A Unified Platform for Task Scheduling on Heterogeneous Multicore Architectures* [Euro-par'09].
  - Only list scheduling and without taking data transfer times into account
- Static scheduling heuristics for heterogeneous processors
  - H. Oh and S. Ha. *A static scheduling heuristic for heterogeneous processors* [Euro-Par '96], H. Topcuoglu, S. Hariri, and M.-Y. Wu. *Task scheduling algorithms for heterogeneous processors*. Heterogeneous Computing Workshop, 1999.
  - Formal approaches without implementation, no runtime assignment

Static Assignment Problem 1: which is best?

different workloads have different best static assignments on heterogeneous processors

different static assignments on GPU and CPU per workload ....



6 different best static assignments (sa) for 8 different workloads

Static Assignment Problem 2: scaling

- experiment (previous graph):
  - 1 to 8 streams
  - 2 resolutions
  - 8 different load distributions over GPU and CPU
  - # static assignments ~ 100 (points in the graph)

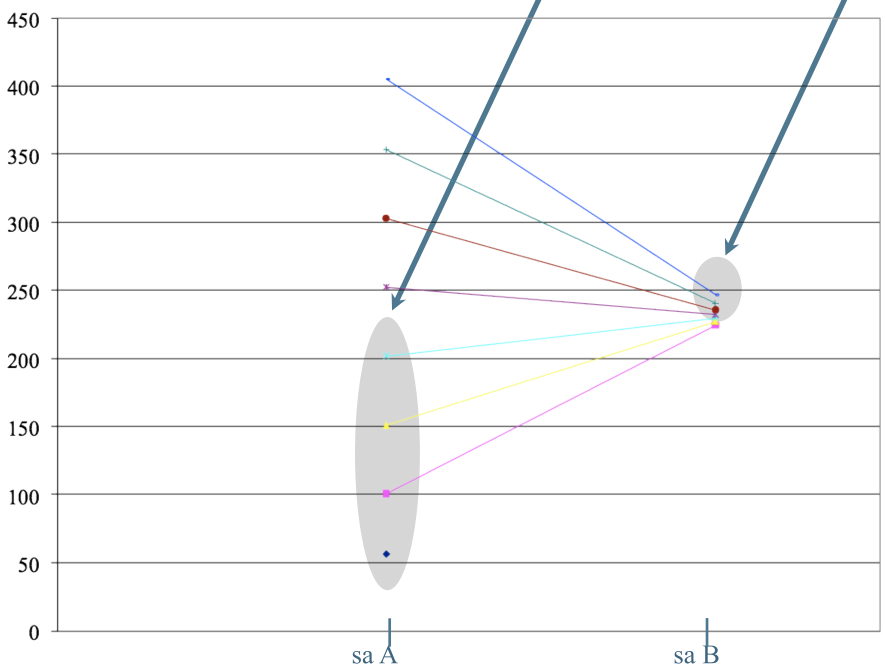
- professional video processing
  - 1 to 64 streams
  - 4 resolutions
  - 64 different load distributions over GPU and CPU
  - # static assignments ~108

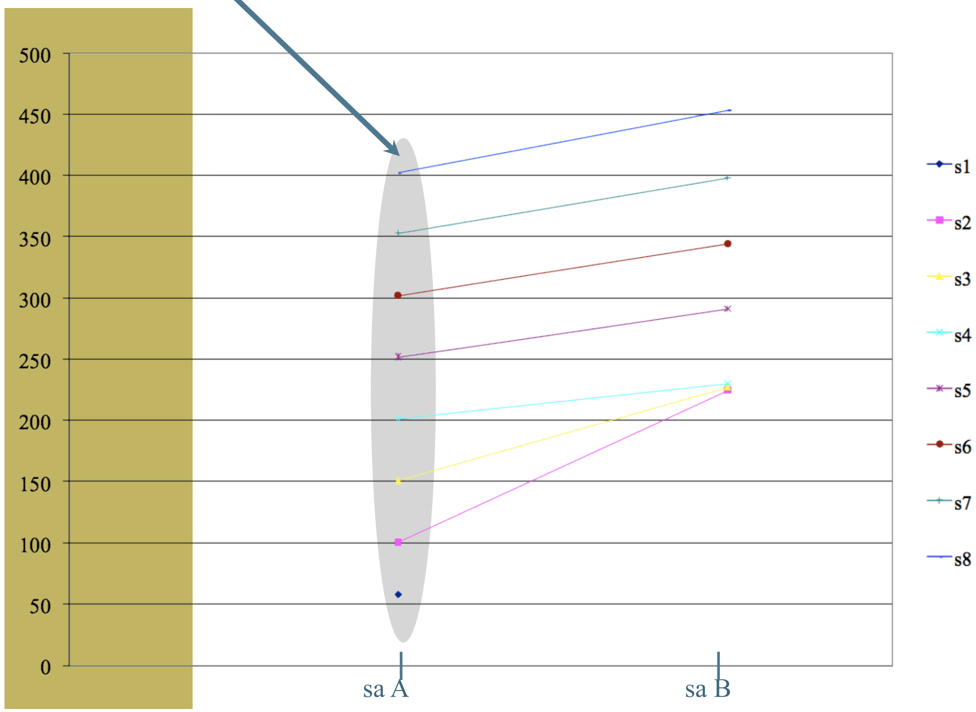
static assignment problem 3: heterogeneity

variations in configurations of processors have different best static assignments for same workloads

best static assigments on **1 GPU and 2x 4-core CPU**:
> 4 tasks: sa A
≤ 4 tasks: sa B

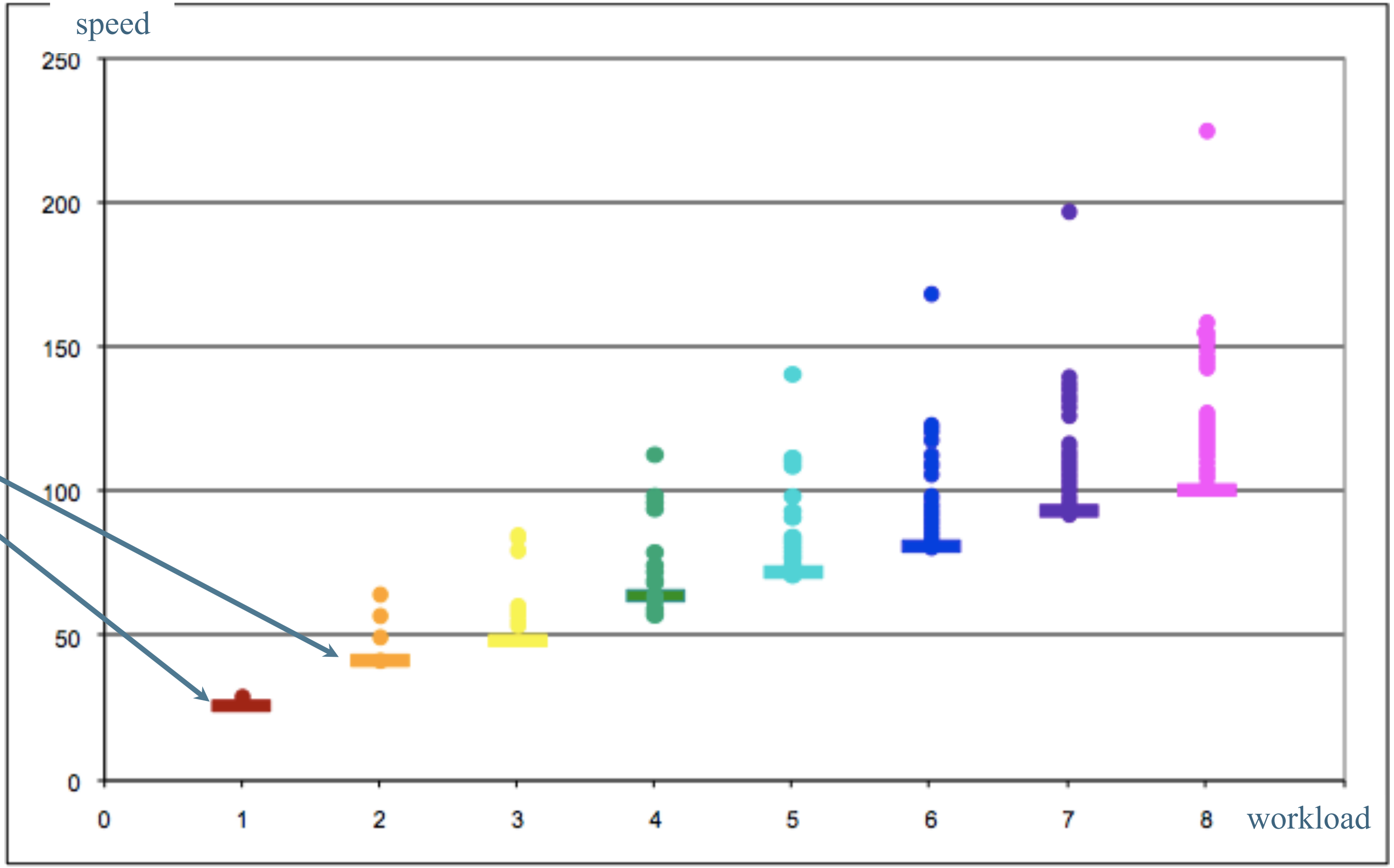
best static assignment on **1 GPU and 4-core CPU**:
sa A





ARES' Adaptive runtime resource management

ARES run-time load balancing for all workloads is almost always better than the best static assignment per workload



ARES' approach is portable across platforms

ARES run-time load balancing is portable to different configurations of heterogeneous processors:

exact same software stack adapts to underlying heterogeneous processors and achieves best performance all the time

(horizontal lines)

run-time load balancing on

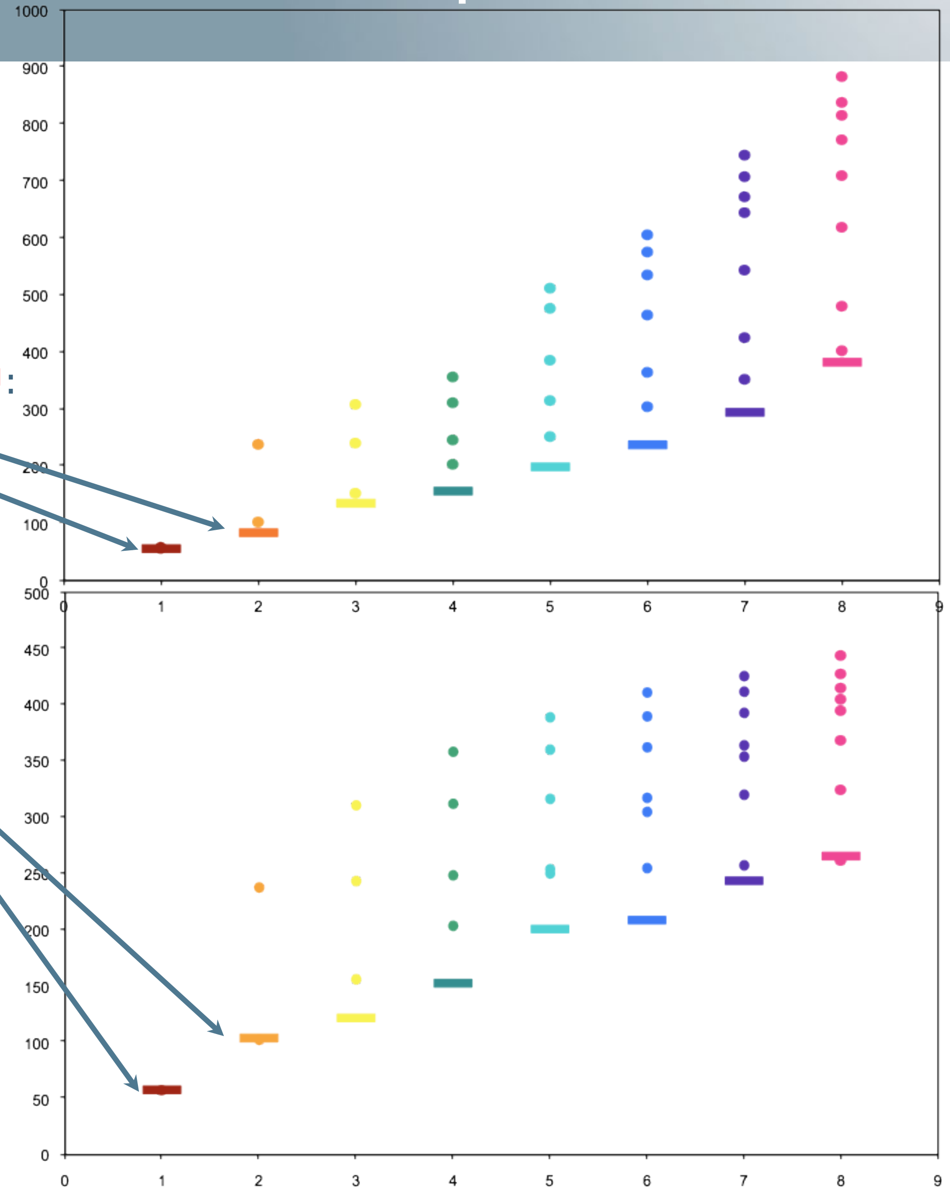
1 GPU and 2x 4-core CPU:

1 to 8 streams

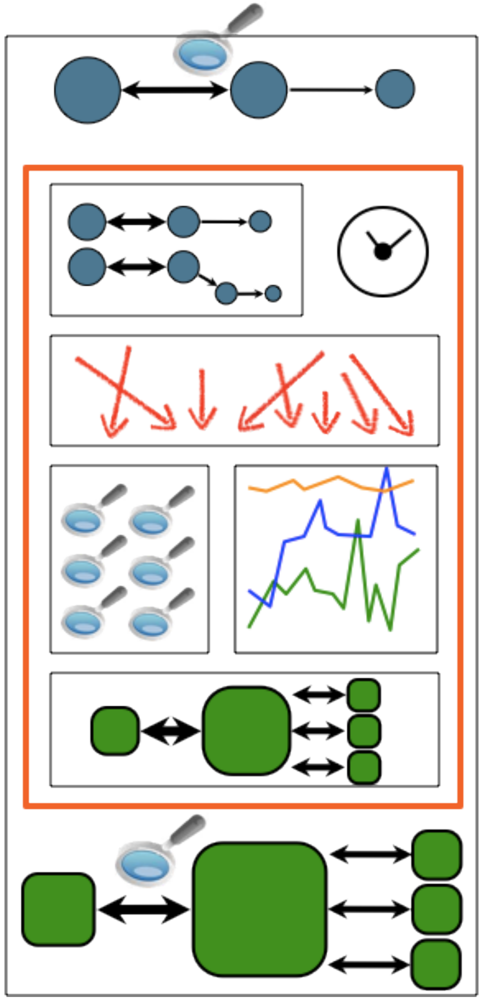
720p resolution

run-time load balancing on

1 GPU and 4-core CPU:



ARES Runtime Resource Management: parts



- Monitor
  resource assignment and usage
- Represent
  monitored information
- Decide assignment at runtime
  - use monitored information
  - predict, learn, adapt, ...
  - Pluggable strategies with different trade-offs

Monitoring and Representation Examples

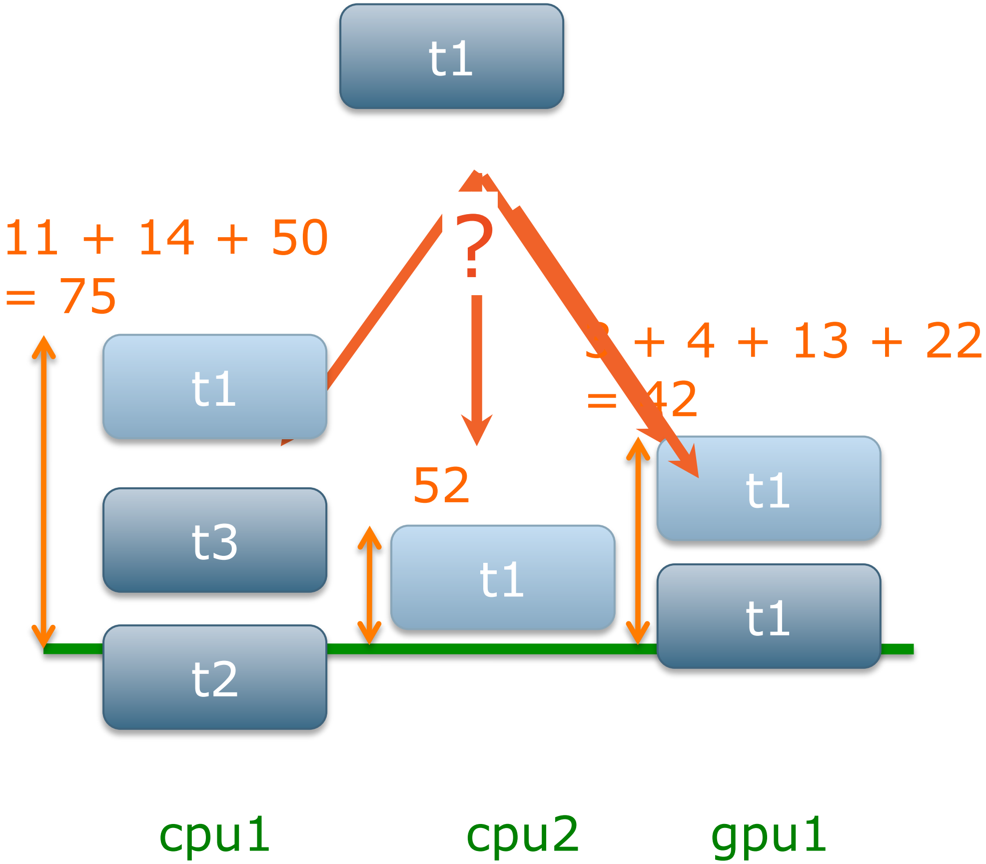
- We monitor:
  - execution time of a component on a processing element
  - data transfer times between two connected components executing on different type of processing element
- We represent:
  - Average time + standard deviation per component and per processing element

Task	PE	time	Dev.
t1	cpu1	50	9,3%
t1	cpu2	52	5,6%
t1	gpu1	4	4,1%
t1	->gpu	13	12,8%
t1	gpu->	32	8,4%
t2	cpu1	134	3,6%

Assignment Strategies

- Can use the following information:
  - Hardware metadata: static and runtime
  - Software metadata: static and runtime
- Have to respond to assignment requests
  - Fast response is required
- Different algorithms are possible
  - Static (up-front) decision: no runtime adaptation (SoA)
  - Generic: fastest available, first finished
  - Domain-specific: prefer-GPU-sequence
  - Machine learning

Example: First Finish Strategy



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t1	->gpu	13	12,8%
t1	gpu->	32	8,4%
t2	cpu1	134	3,6%
t3	cpu1	14	6,2%
…			

Implementation

- ARES Runtime resource manager implementation:
  - Dynamic library for Unix (Linux, OS-X) and Windows
  - C and C++ header for integrating with applications
  - Uses Boost shared memory to store values
  - Low-overhead (0,01%)
- Used with:
  - AVC Encoder (CUDA-accelerated motion estimation)
  - GStreamer applications
  - Imec in-house multimedia framework in .Net on Windows

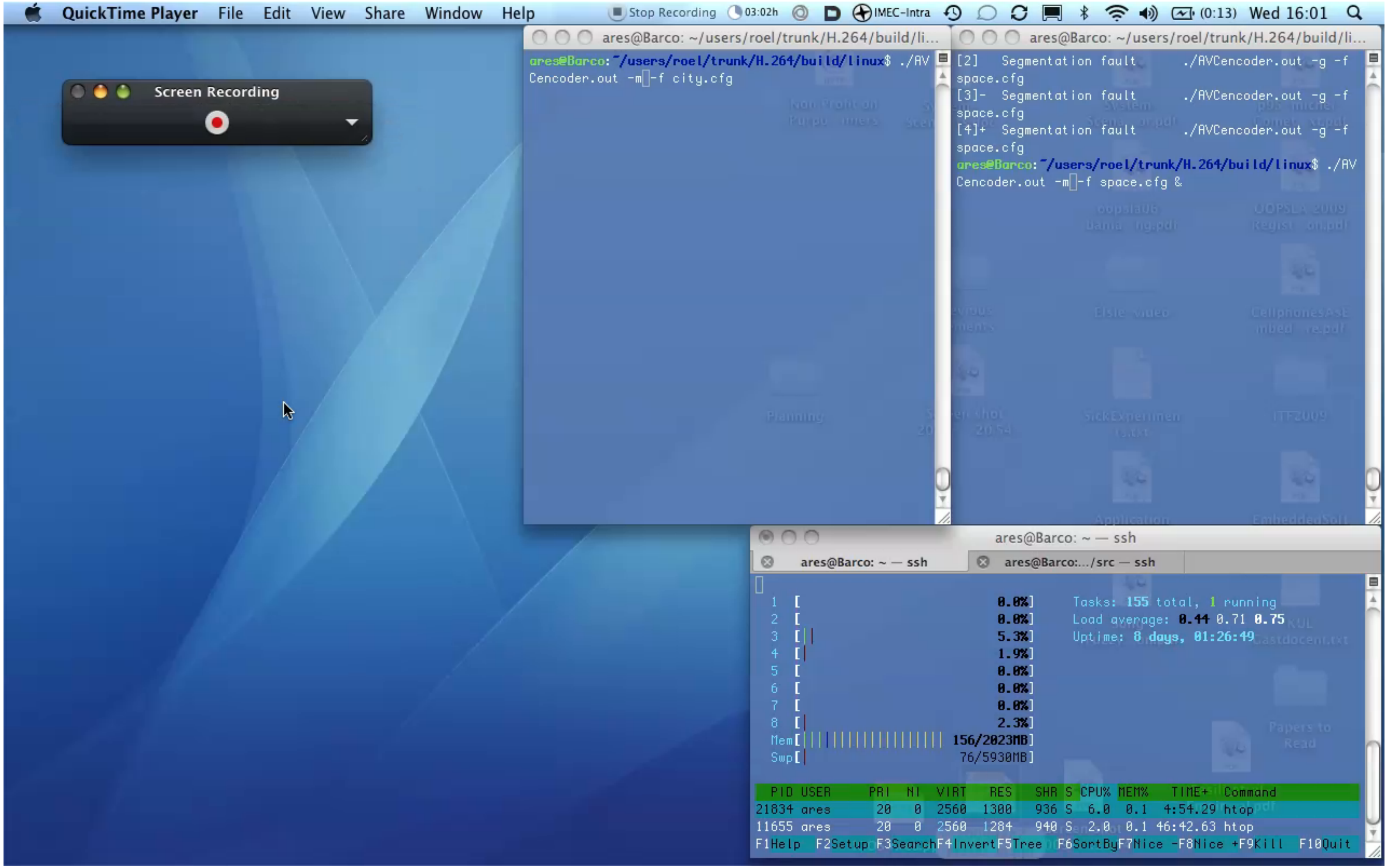
Making the AVC Encoder runtime managed?

```
...
//ask RRM to decide between GPU or CPU
proc_type  = rrm_get_processor(encID);
if (  RRM_PROC_TYPE(proc_type) == RRM_PROC_GPU  )
     cuda_me = 1;
else
     cuda_me = 0;

start2 = RDTSC ();
if (cuda_me == 1) {
  start = RDTSC ();
  GPUinit();
  cuda_motion_estimation();
  GPUExit();
  g_total_MEtime = (RDTSC () - start);
}
else {
  ((ARMVCM4P10_MESpec *)encInfo.params.meSpec)->no_gpu_data();
}
...

//update RRM execution time
update_kernel_timing(encID, proc_type, g_total_MEtime);
...
```

2 lines

1 line

City + Space: runtime managed



But...

- … what runtime management strategy works best for my application ?

- … will my existing application benefit from runtime management ?
- … will my new application benefit from runtime resource management?
- … what if my clients use a dualcore CPU and 2 GPU’s ?

Exploration Tool

- Compare different runtime resource management strategies
- How?
  - Model software at high-level (connected components).
  - Decorate nodes with timing information:
    - Average execution times per processing element supported;
    - Data transfer Times between different processing elements.
    - These timings come from the runtime manager, from other profiling tools, from experience, or even from guestimates.
  - Model kind and number of processing elements.
  - Select the strategies you want to compare.
- Result?
  - Exploration tool simulates the execution for each strategy and outputs information that can be plotted (dropped frames, late frames, platform utilization)

Exploration Tool Input

Application 1

Source
Execution time:
CPU: 0.011ms

Demux
Execution time:
CPU: 0.00163ms

Scaler
Execution time:
CPU: 0.115ms
GPU: 0.0129ms
Data Transfer Time:
CPU->GPU: 0.079ms
GPU->CPU: 0.17ms

Sink
Execution time:
CPU: 0.51ms

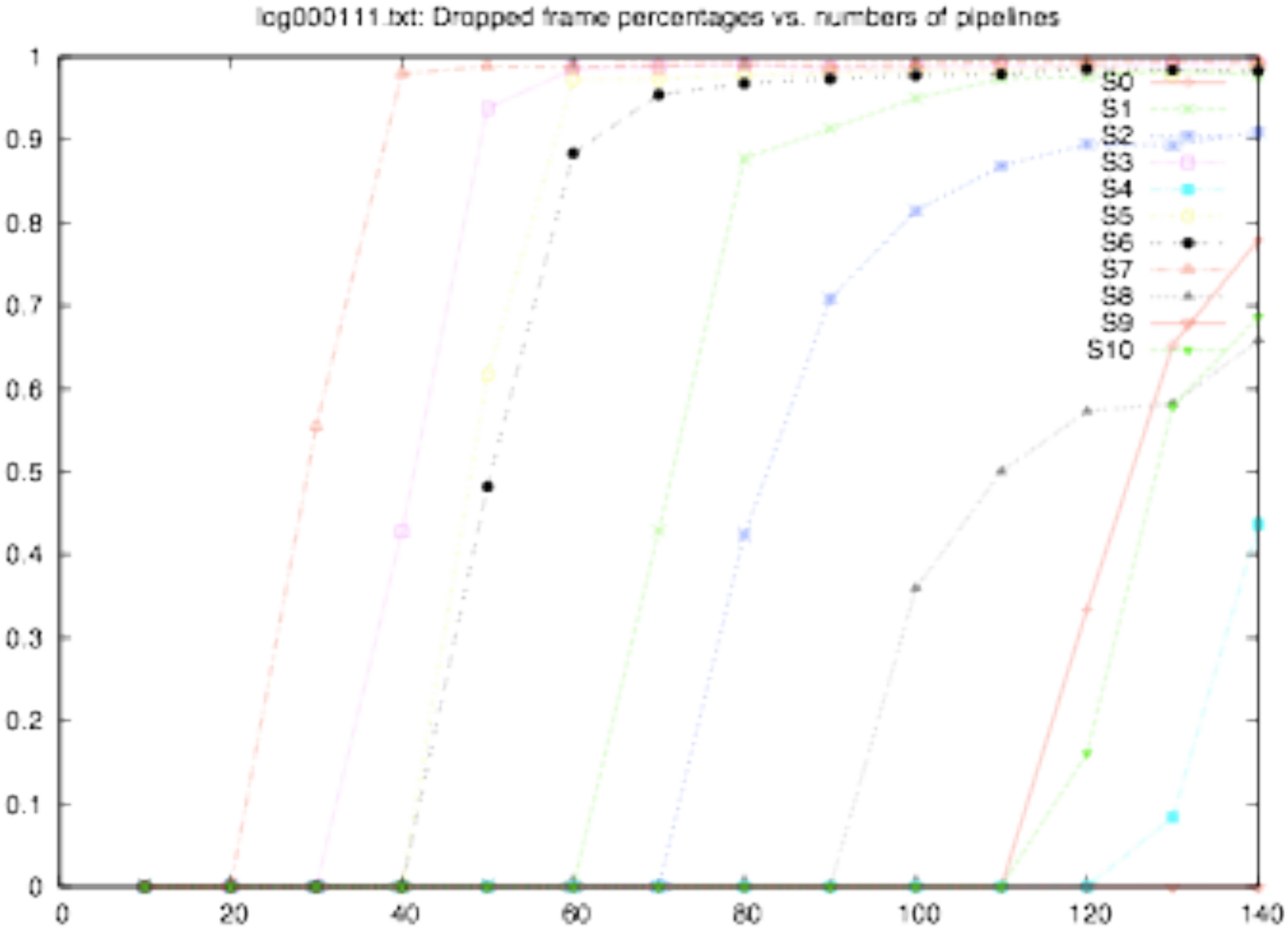
Application 2

Encoder
Execution time:
CPU: 0.43ms
GPU: 0.074ms
Data Transfer Time:
CPU->GPU: 0.085ms
GPU->CPU: 0.46ms

Hardware Description

8 CPU
1 GPU
2 DMA

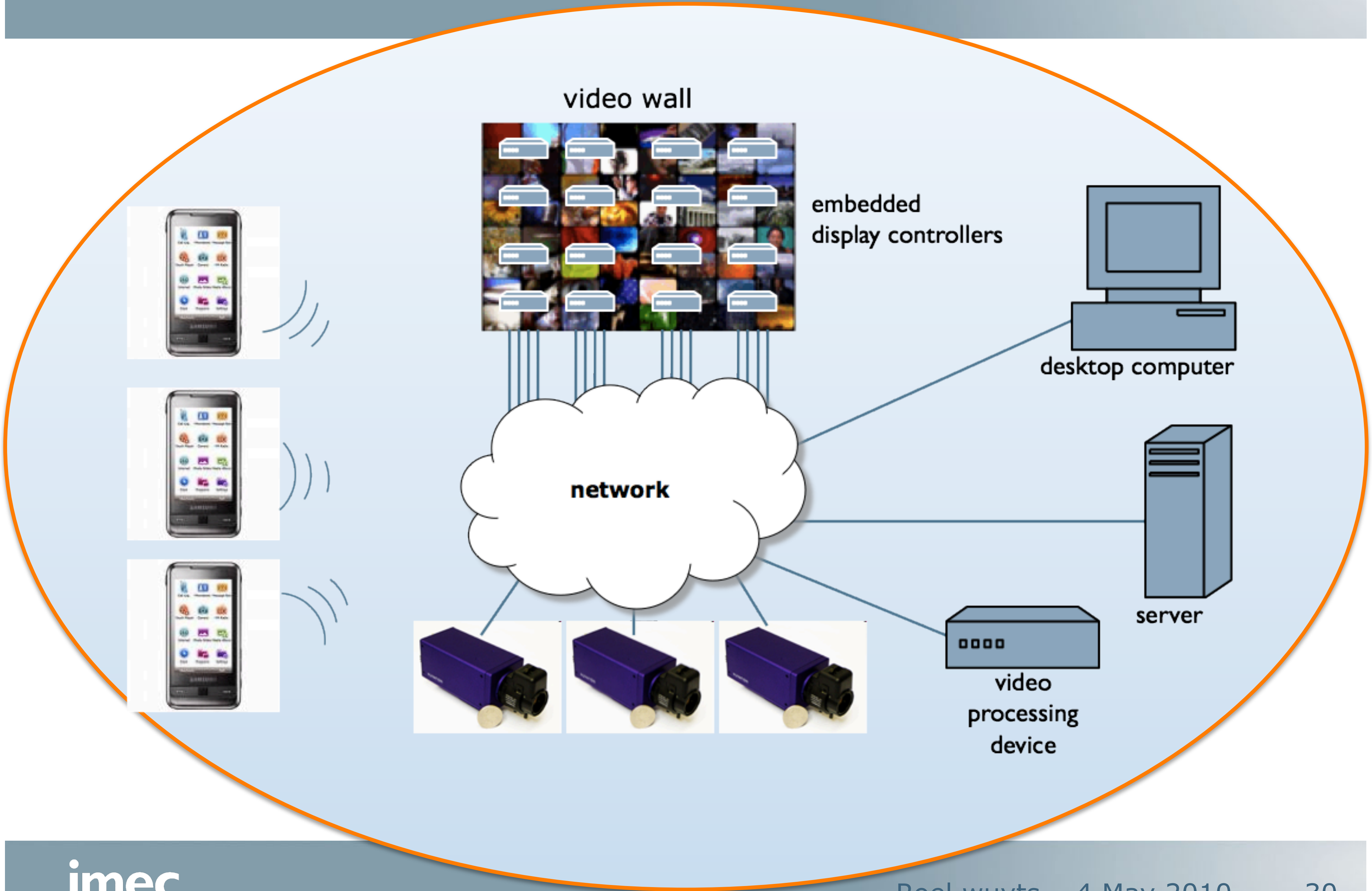
Plotted outputresult



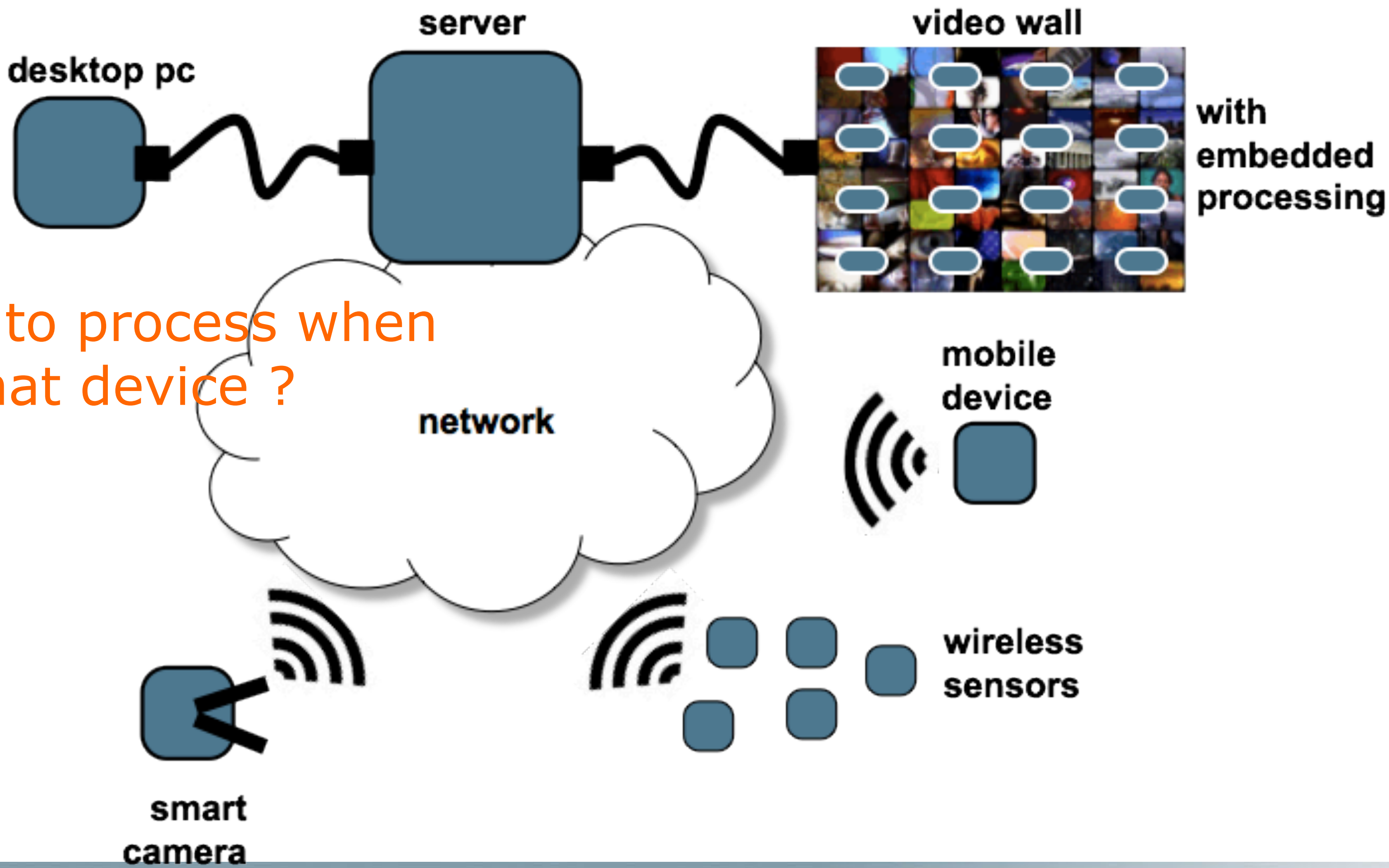
Device-level adaptive resource management

- Static assignments exhibit problems
  - Different solutions for different workloads or other runtime variability
  - Do not scale (exploration space explosion)
  - Different solutions for different platforms
- Runtime resource managed solution adapts to different conditions
  - Runtime variability
  - Heterogeneous platforms

Context: Networked Video Processing

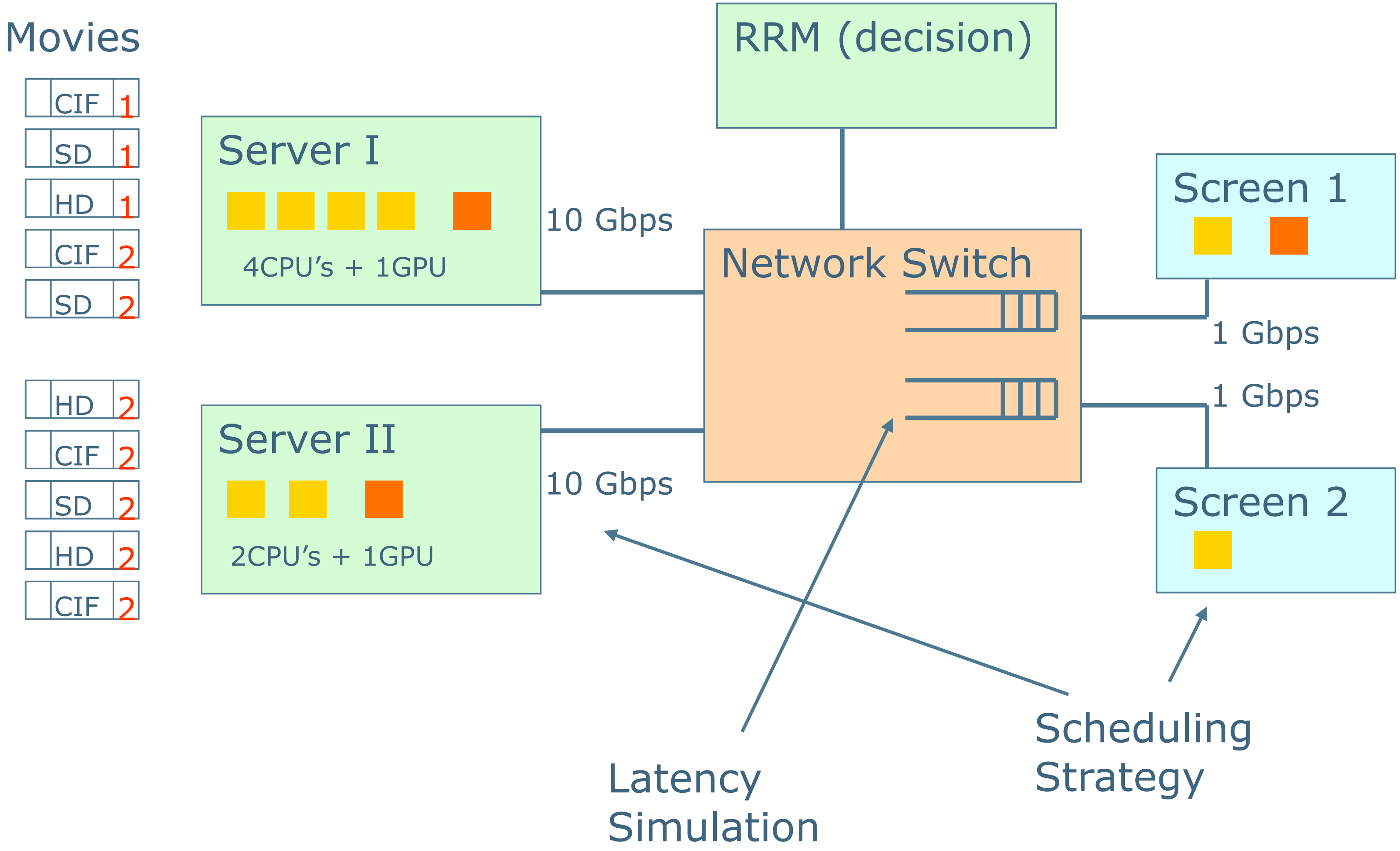


Network: Connected heterogeneous devices

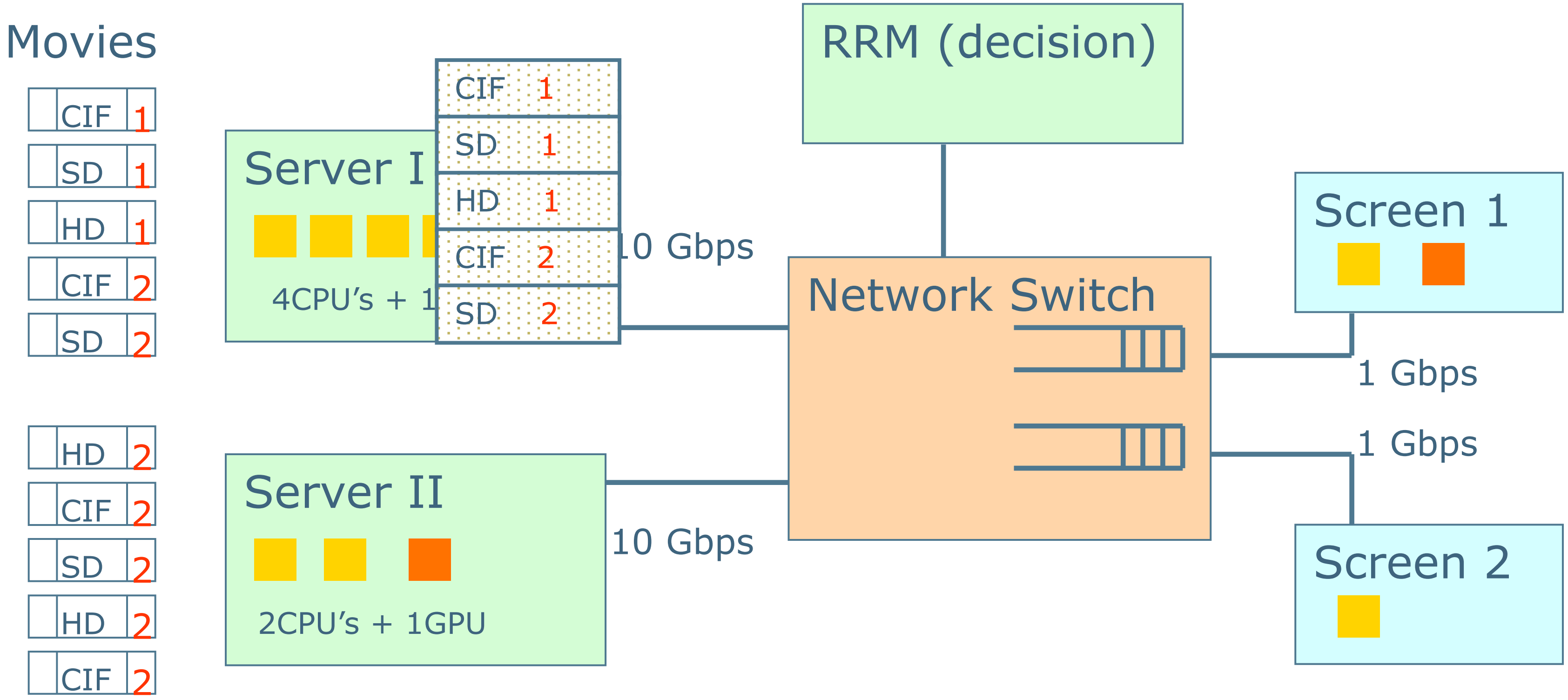


What to process when
on what device ?

System-wide Resource Allocation

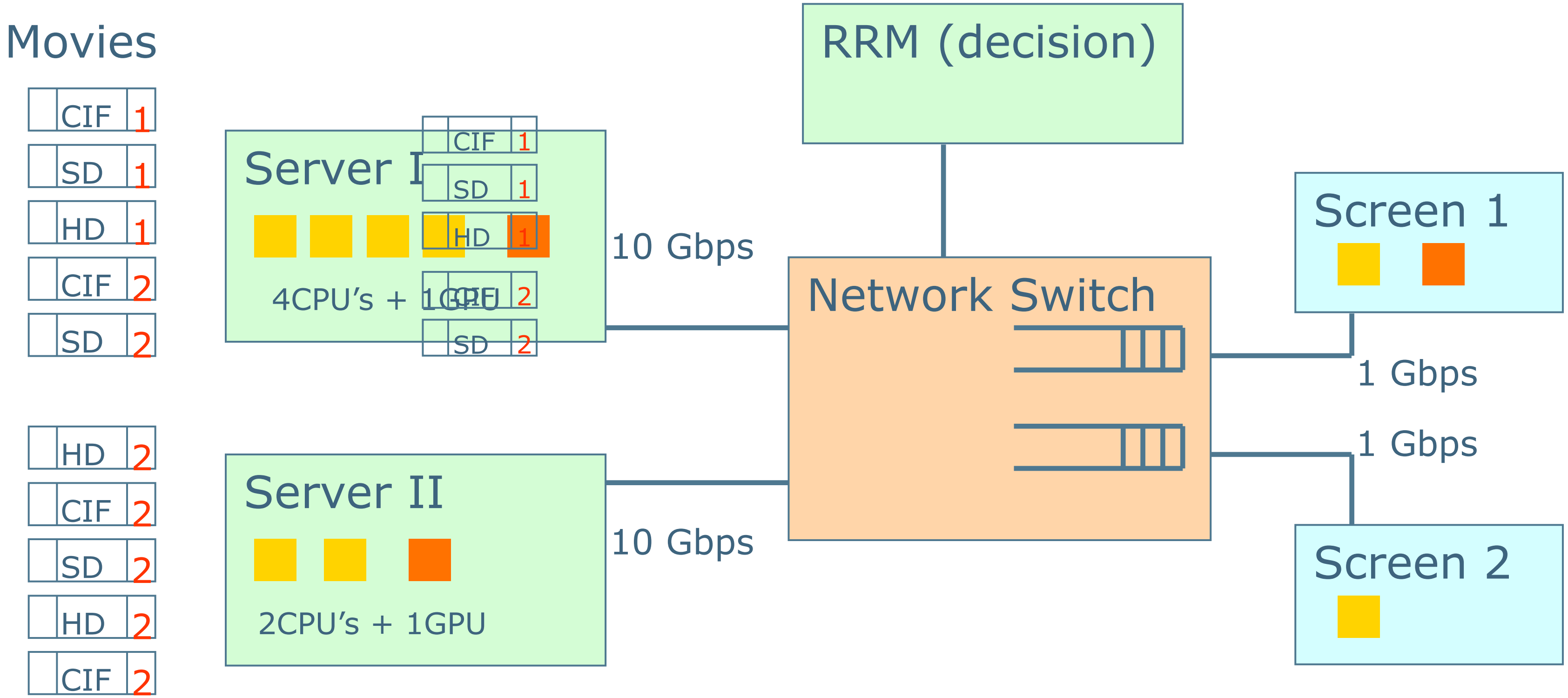


Possibility: Everything decoded at server, raw data to client



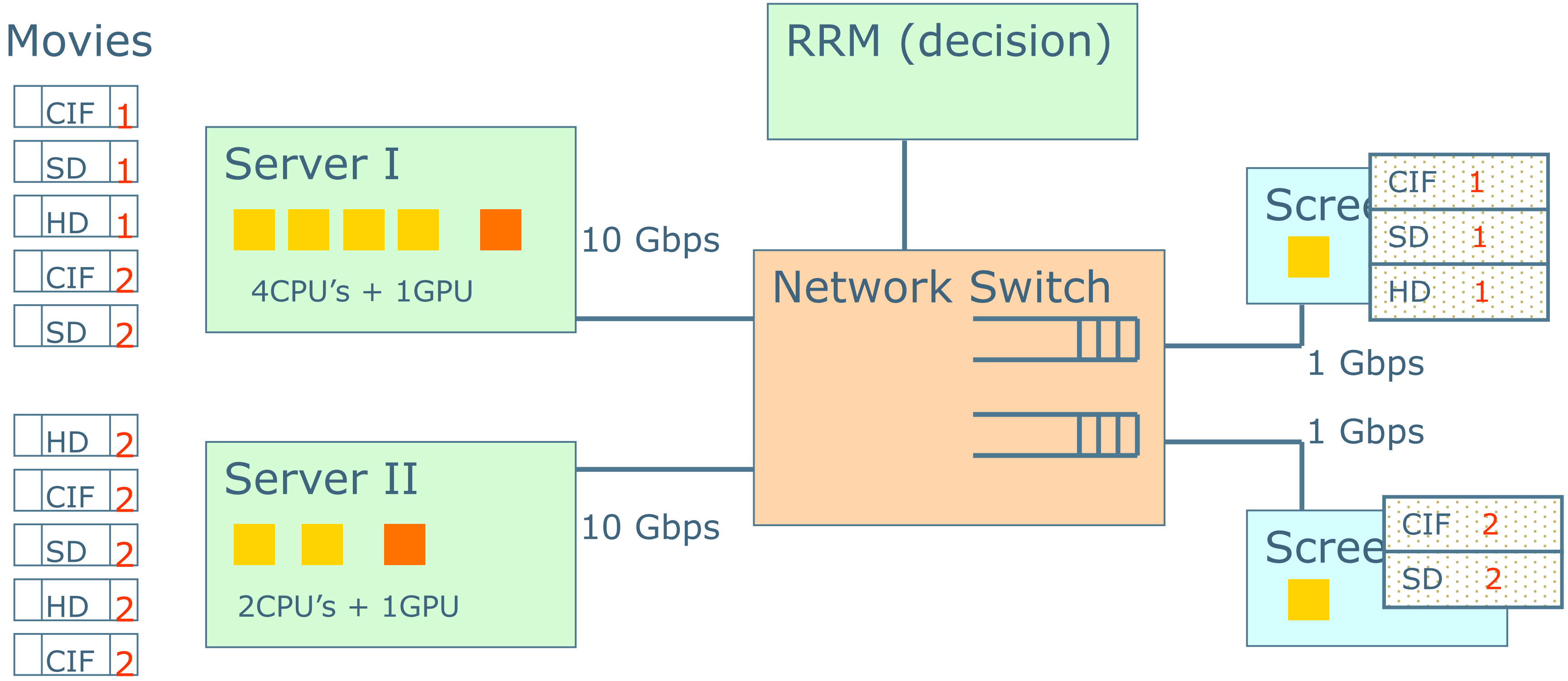
(-) Increases Bandwidth and network latency
(+) No processing cost at client

Possibility: Everything trans-coded at server, lower resolution sent to client



(+) Reduces Bandwidth and network latency
(+) Lower processing cost at client
(-) Increases processing cost at server

Possibility 4: Everything fully decoded at client



(-) All processing at client, might miss deadlines
(+) No BW or latency increase

network-level: first results

- distributed processing of video processing applications on server or client
- trade-off between processing at server, processing at client or transcoding to lower quality
- adaptive run-time resource management - using a mixture of the above - gives good results:

	Processed at Server	Processed at Client	Transcode	Mixed Processing
Resolution/Quality	High	High	Low	Medium-High
Missed Streams	6 (limited bw)	5	0	0
BW (Gbps)	2.7	0.6	0.08	0.95
Latency (ms)	92	10	2.9	33

Networked Video Processing: Future Work

- Discover Distributed Processing Strategies
  - Trading of bandwidth, processing power and quality
- Implement
  - Currently extending the device-level manager

Conclusion

- Problem: how to develop software that runs on heterogeneous devices
  - At SoC level
  - At Device level
  - AtNetwork Level
- Solution: runtime decision strategies decide what software component uses what resource

- Meta Remark: versatility of your studies make you valuable assets
- Meta Meta Remark: Choose according to Flexibility versus Pay