An Application-oriented Approach for the Generation of SoC-based Embedded Systems

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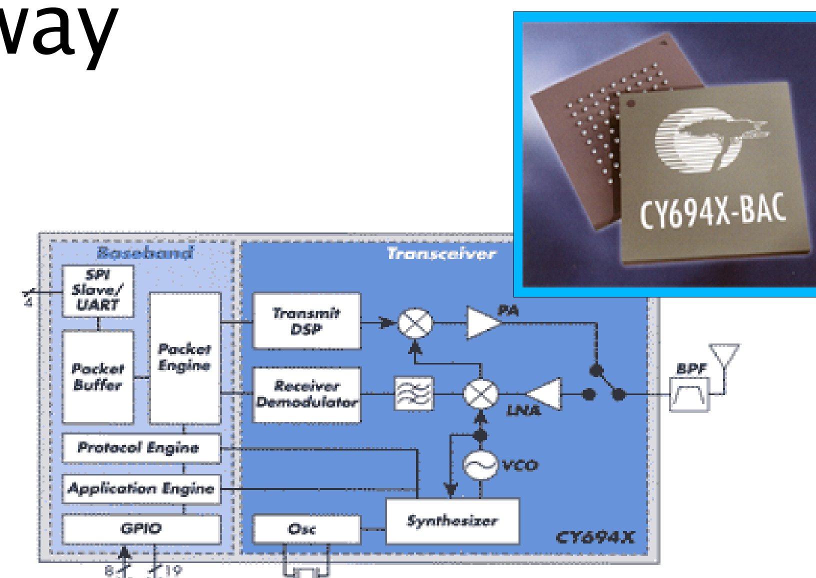
System-on-Chip

- Advances on programmable logic devices are enabling developers to integrate complex hardware designs in a single silicon pastille
- Soft-core processors can sustain such designs in a flexible way

Embedded systems implemented as SoCs



Operating System

- The more complex the SoC, the greater the probability it will need some sort of run-time support system
  - Operating system
    - Abstract underlying hardware
    - Sustain a programming model for applications
  - Applications
    - High-level programming languages
    - Reusable software artifacts
- Ordinary operating systems cannot go with the dynamism of SoCs

  "the current specification techniques for sw-hw interfacing are so far from the ideal plug-and-play" [Neville 2003]

SoC x OS: the Traditional View

- Most currently available co-design tools and methodologies pay little attention to run-time support systems
  - Platform-based design

    "In essence, a platform is a frozen architecture. Once the architecture is frozen, you may standardize the interfaces and give the engineers some choice of building blocks" [Smith 2004]
  - Traditional EDA tools are quite restrictive as regards the development of run-time support systems
  - Run-time support is usually regarded as part of application's duties

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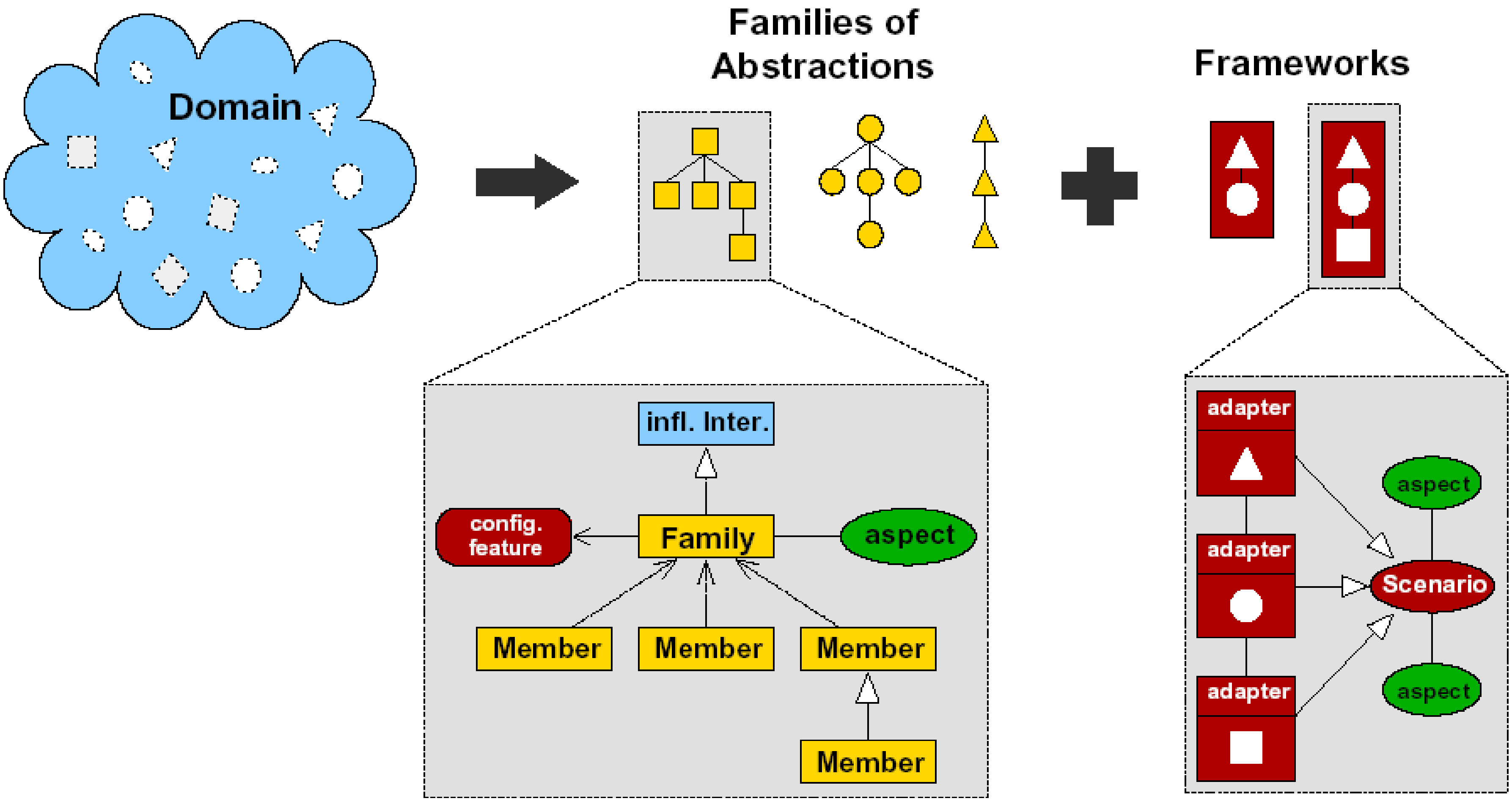
SoC: the AOSD View

- AOSD was born as an component-based system software development methodology
  - Domain engineering methodology
- Soft IPs are much like software components
- Therefore AOSD should be able to guide the component-based design of SoCs as well
  - Hardware IPs build up the machine
  - Software IPs build up the run-time support system
  - Application requirements drive the process
  - Developers can thus concentrate on what really matters: applications

Application Oriented System Design

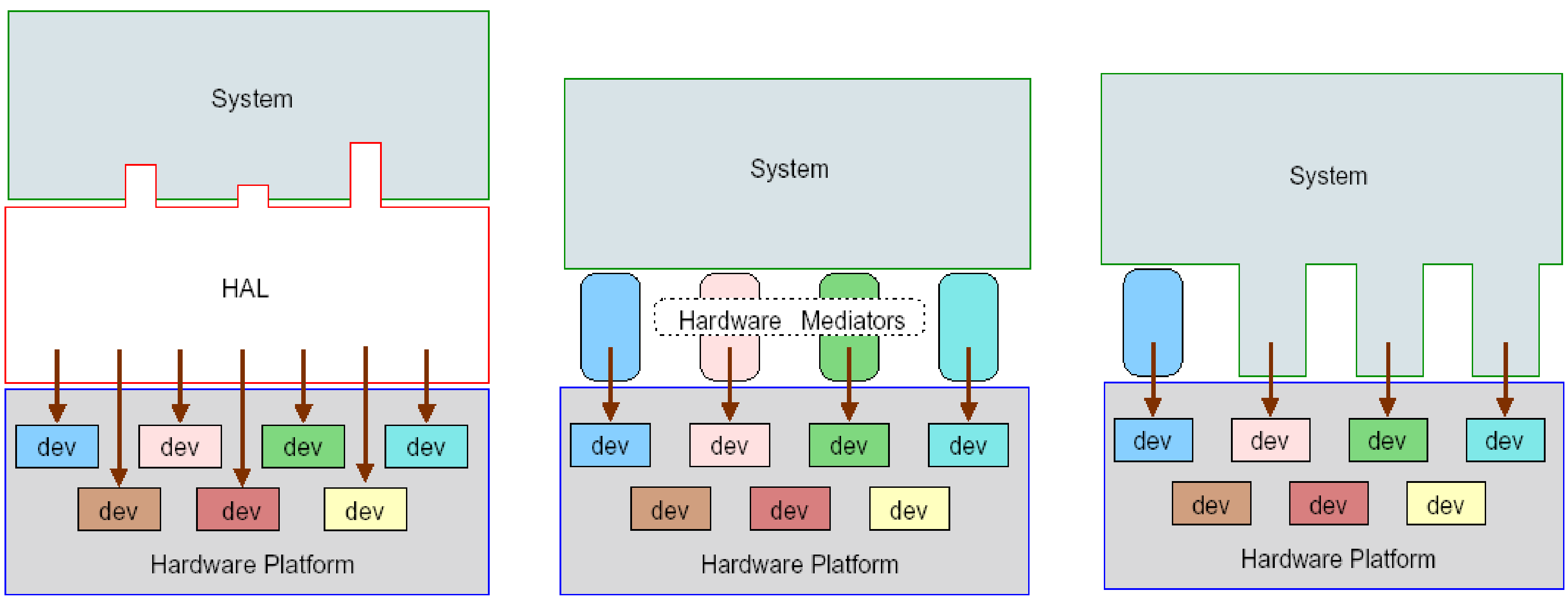


The EPOS System

- Embedded Parallel Operating System
  - A collection of software components designed according to AOSD principles
  - A meta-programmed framework
  - A set of tools to assist the selection, configuration and adaptation of those software components
- Portability
  - EPOS abstractions (user-visible software components) interact with hardware components through mediators
  - Hardware mediators sustain an interface contract between system abstractions and the machine

EPOS Hardware Mediators

- Mediators are mostly meta-programmed
  - No unnecessary code like in ordinary HALs
  - As soon as the interface contract is met, mediators "dissolve" themselves inside abstractions



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Hardware Mediators and Software/Hardware Co-Design

- The system/hardware interface resulting from the instantiation of hardware mediators can also be seen as a concrete specification of application requirements as regards the supporting hardware
  - Each selected mediator designates a hardware component
  - Parameters and the invocation scenario of each mediator can be used to infer hardware features

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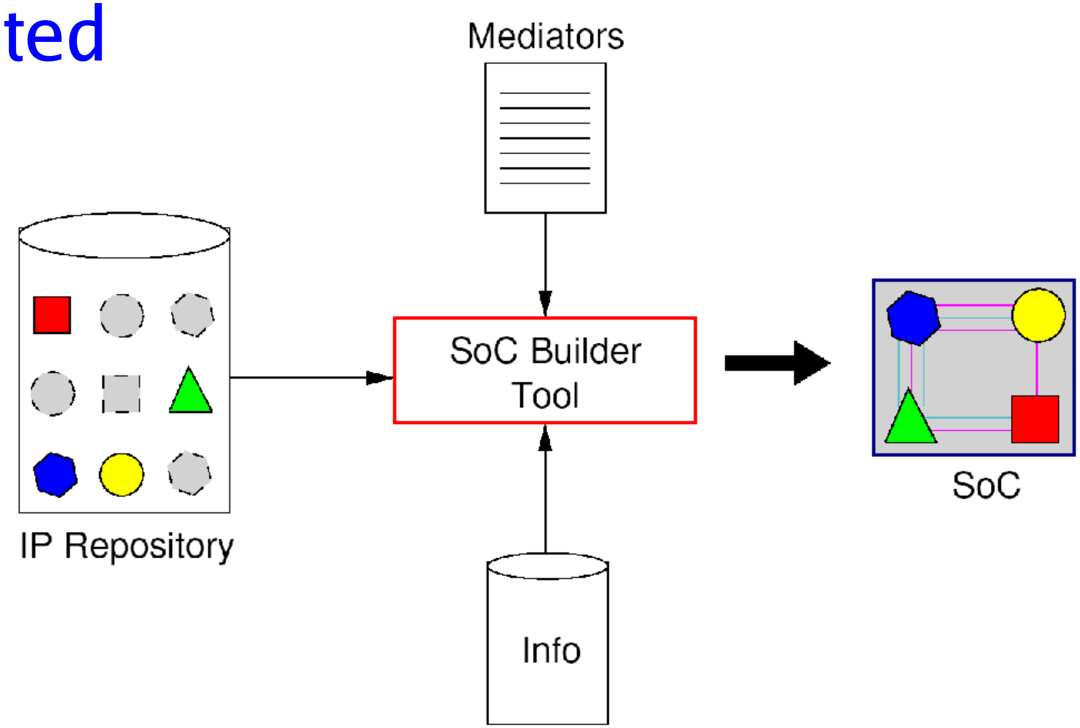
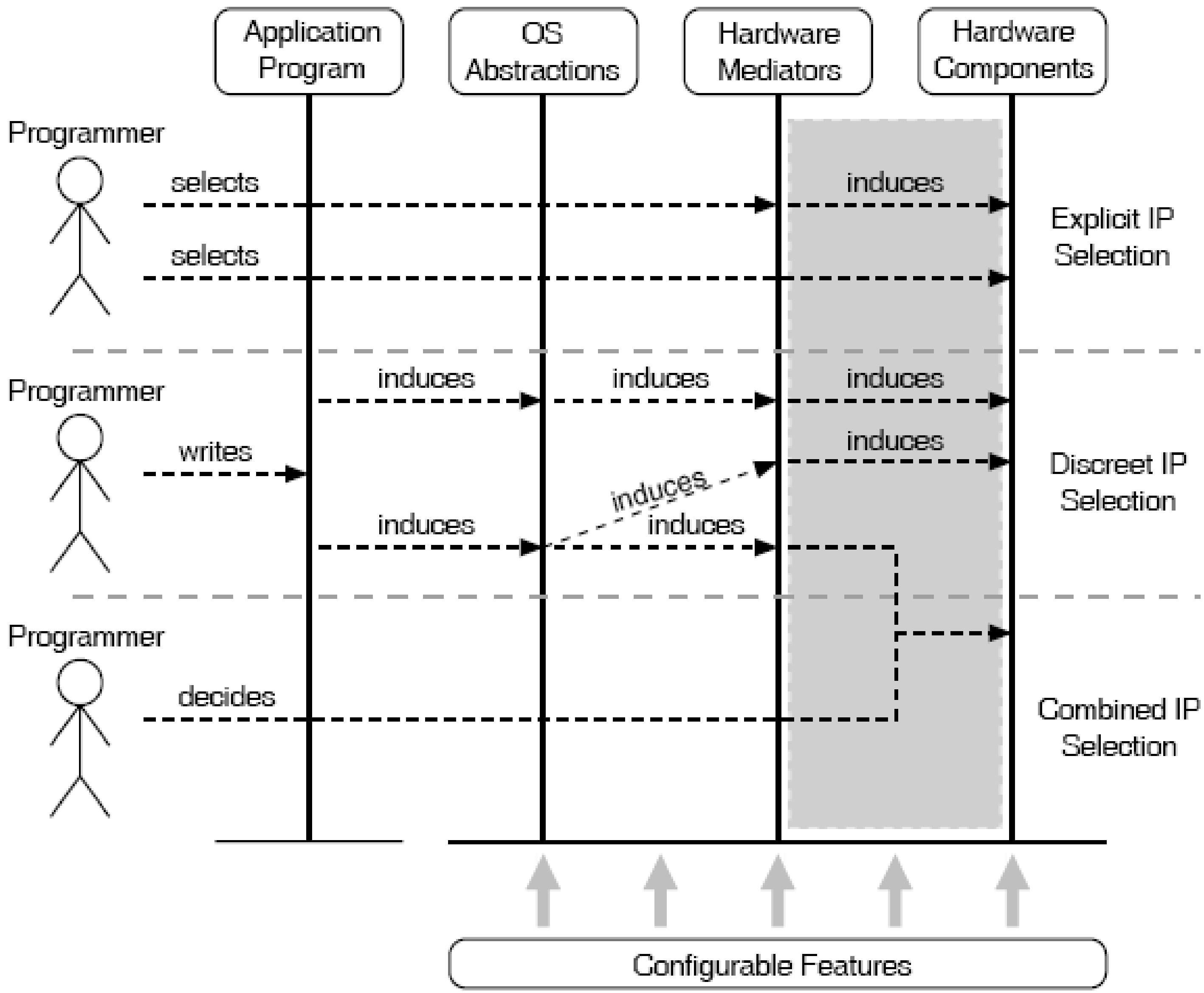
Hardware Components in EPOS

- Hardware mediators can be associated with hardware components (IPs)
  - As soon as a mediator is defined as result of an application requirement, the associated IP is selected



IP Selection Scenarios



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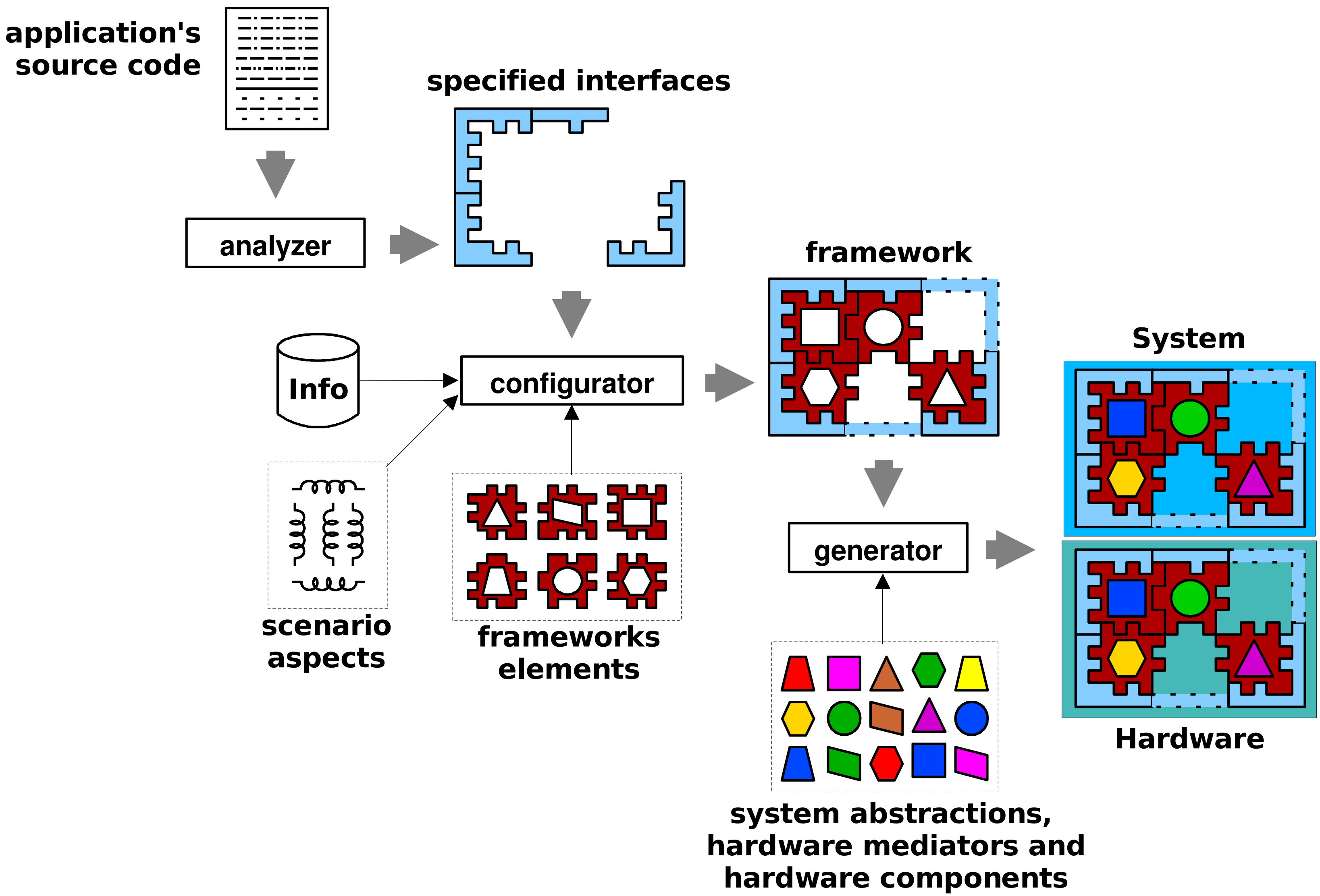
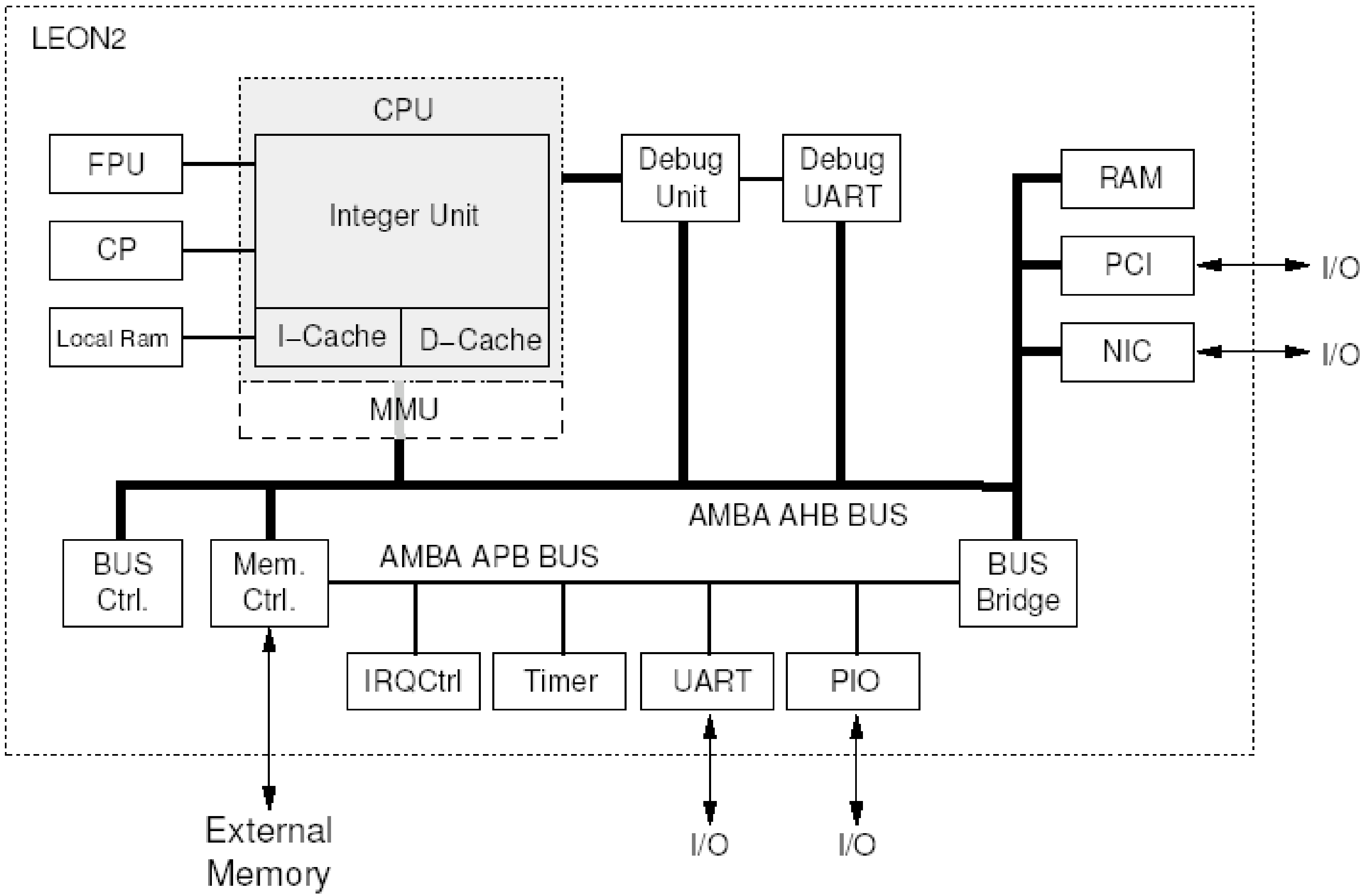
EPOS Instantiation Process



Case Study

- Application
  - Serial relay (bounded buffer)
- SoC
  - Automatically generated by EPOS tools
  - Soft-core decomposed in EPOS components
    - Modular design
    - Standardized BUS
    - Implicit glue-logic
    - GNU GCC (G++)
  - OpenRISC
    - Poor modularization (unnecessary dependencies)
  - Leon2
    - OK

Leon2

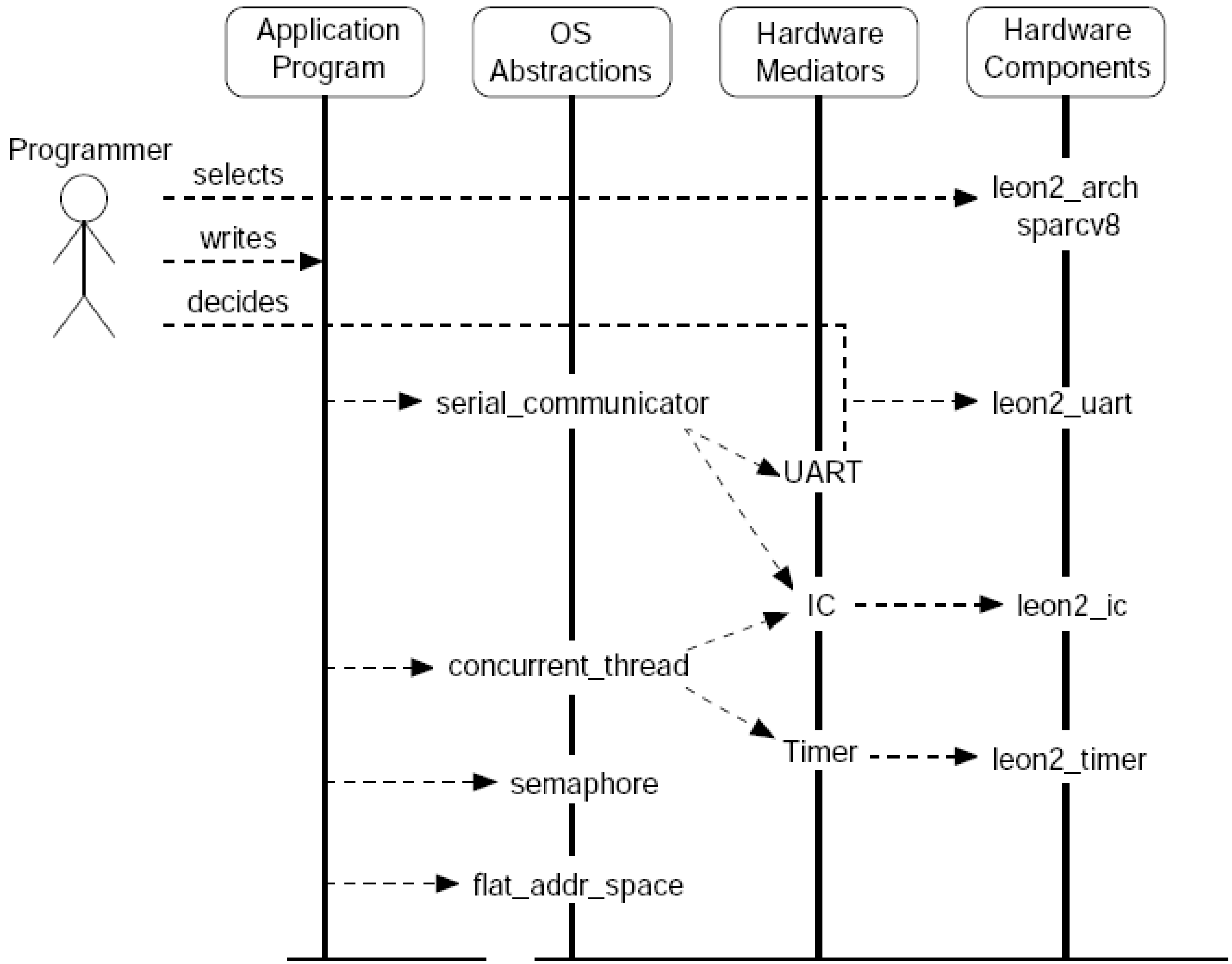

LEON2
CPU
FPU
CP
Local Ram
Integer Unit
I–Cache
D–Cache
MMU
Debug Unit
Debug UART
RAM
PCI
NIC
I/O
I/O
AMBA AHB BUS
AMBA APB BUS
BUS Ctrl.
Mem. Ctrl.
BUS Bridge
IRQCtrl
Timer
UART
PIO
External Memory
I/O
I/O

Application

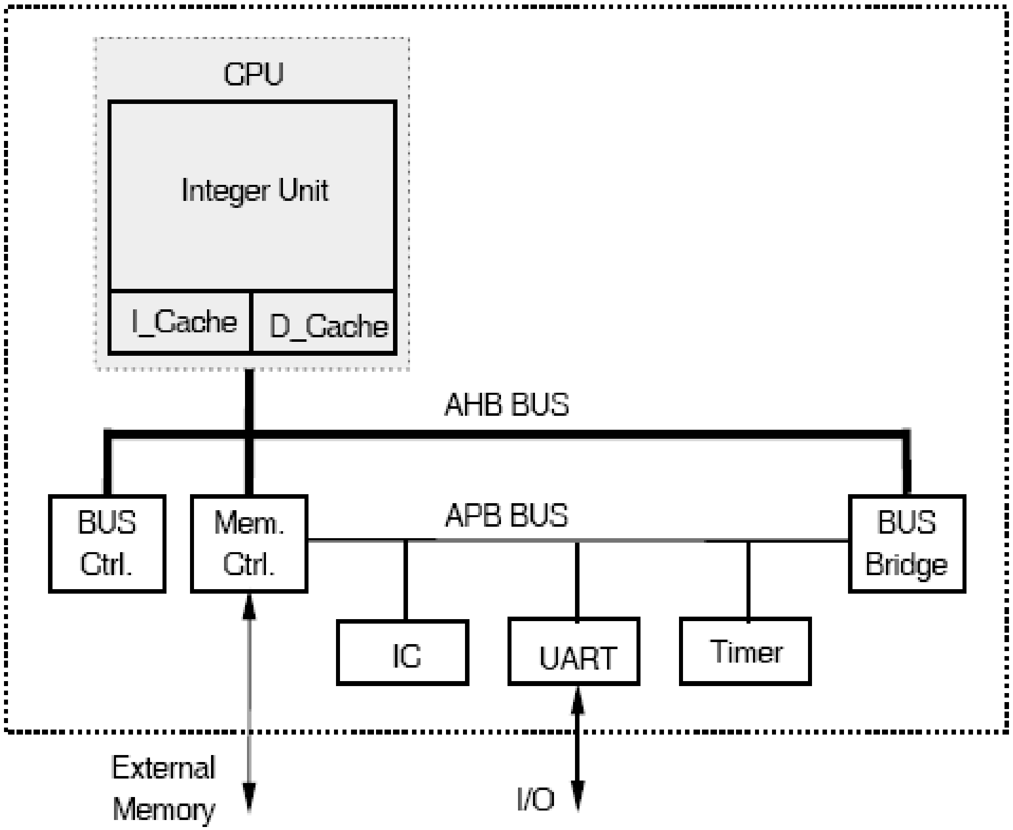
```
char * buf;
Thread * cons;
Semaphore empty(LEN), full(0);
Serial_Communicator comm;

int main() {
  buf = new char[LEN];
  cons = new Thread(&consumer);

  // producer
  int in = 0;
  while(true) {
    empty.p();
    comm->receive(&buf[in], 1);
    // operate on buf[in]
    in = (in + 1) % LEN;
    full.v();
  }
}
```

```
int consumer() {
  int out = 0;
  while(true) {
    full.p();
    // operate on buf[out]
    comm->send(&buf[out], 1);
    out = (out + 1) % LEN;
    empty.v();
  }
}
```

Component Inferring Flow



Tailored Leon2



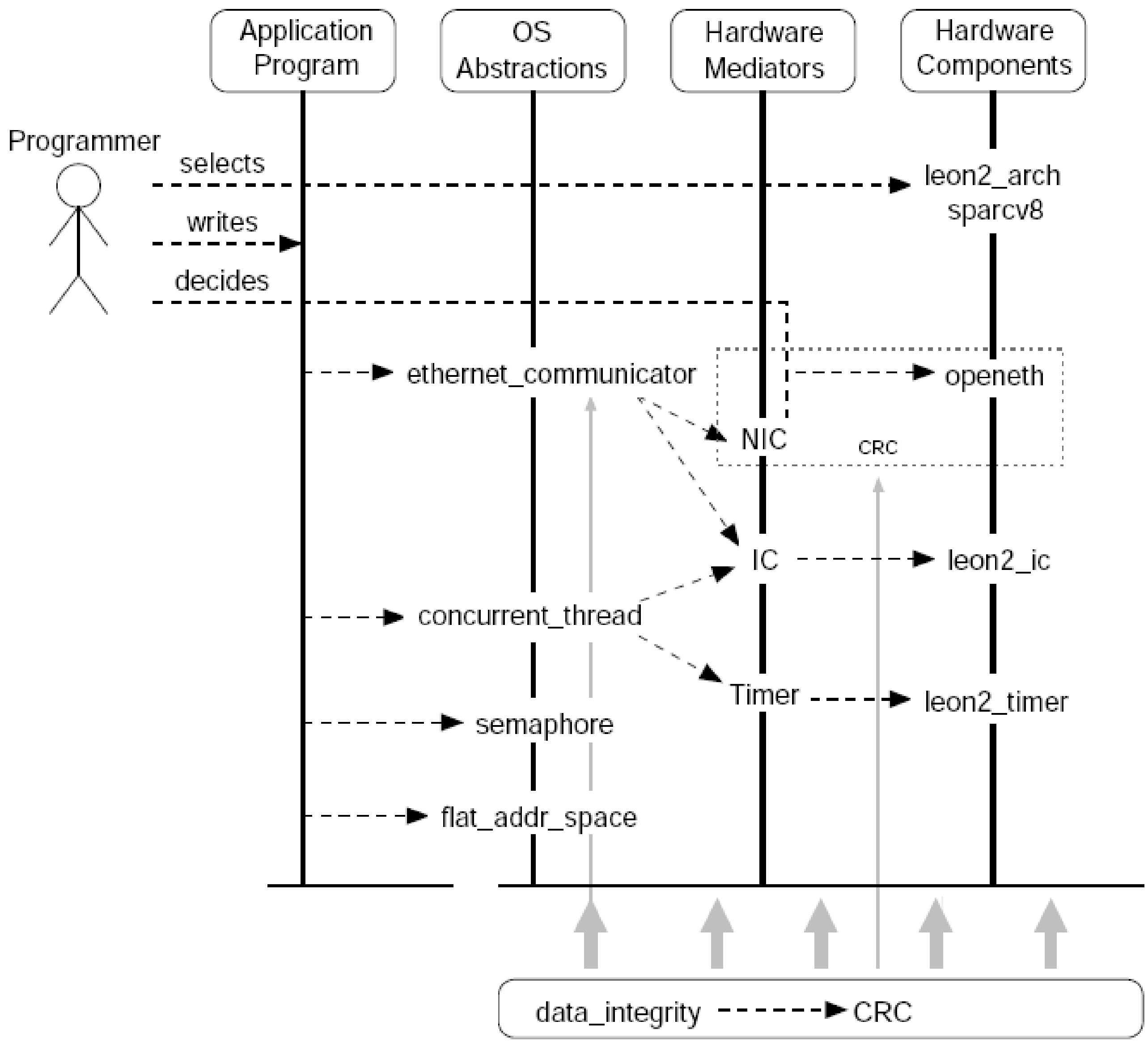
Some EPOS SoC Figures

SoC	Size (LUTs)	Virtex2 Area
Full	14,582	67%
Tailored	6,792	31%

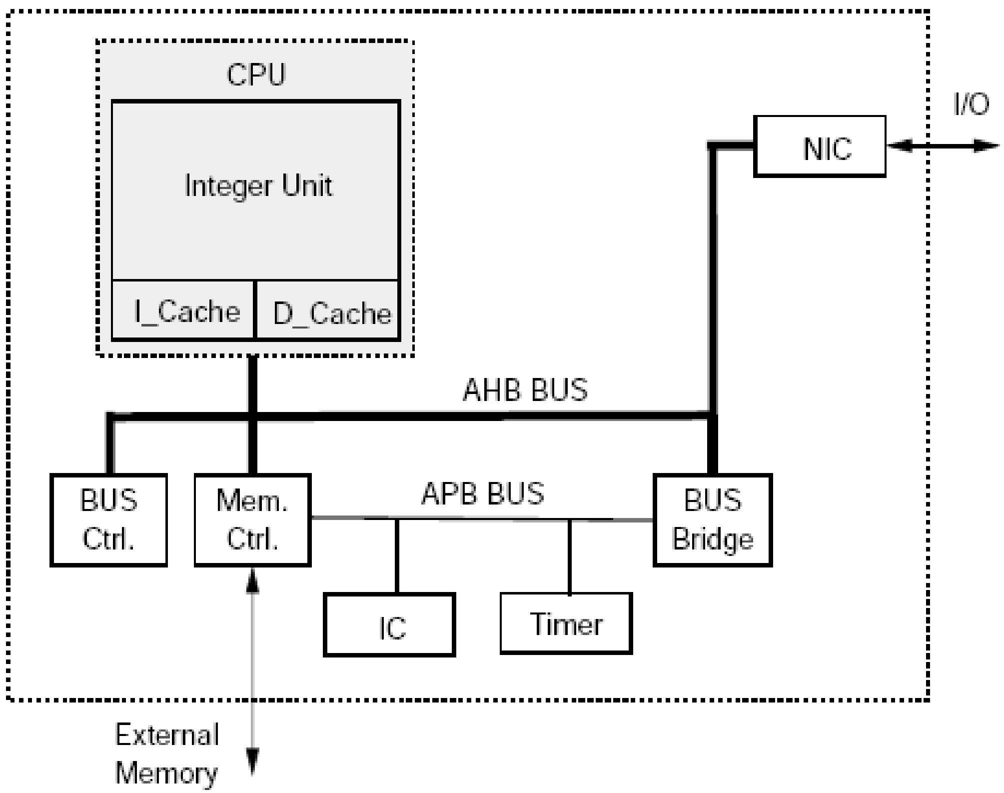
OS	.text (bytes)	.data (bytes)	.bss (bytes)
µCLinux	840,712	44,700	72,649
eCos	17,152	796	34,040
EPOS	8,988	28	8,400

OS	Time (ms)
eCos	132.67
EPOS	45.42

Configurable Feature Deployment



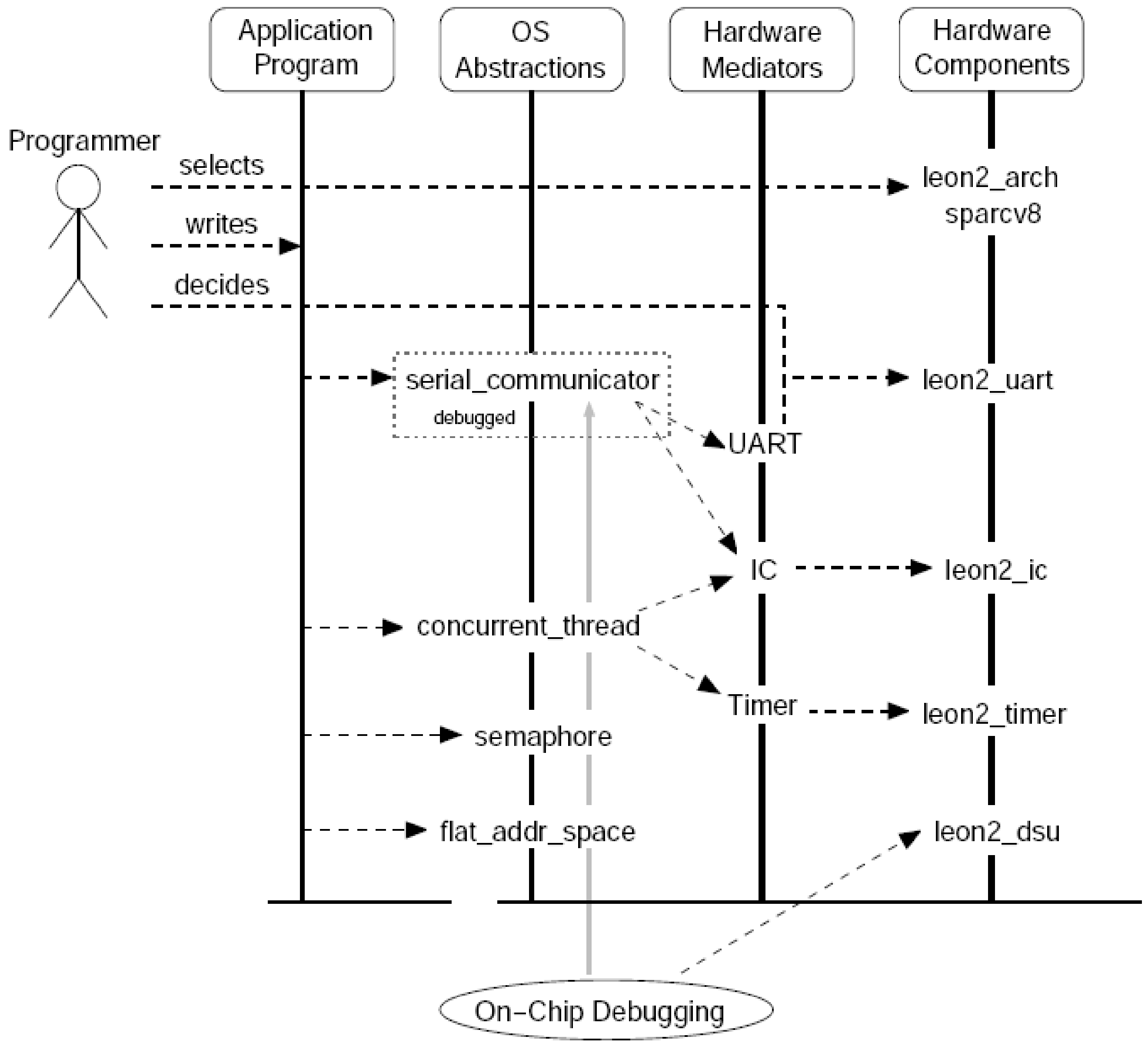
Tailored EPOS SoC



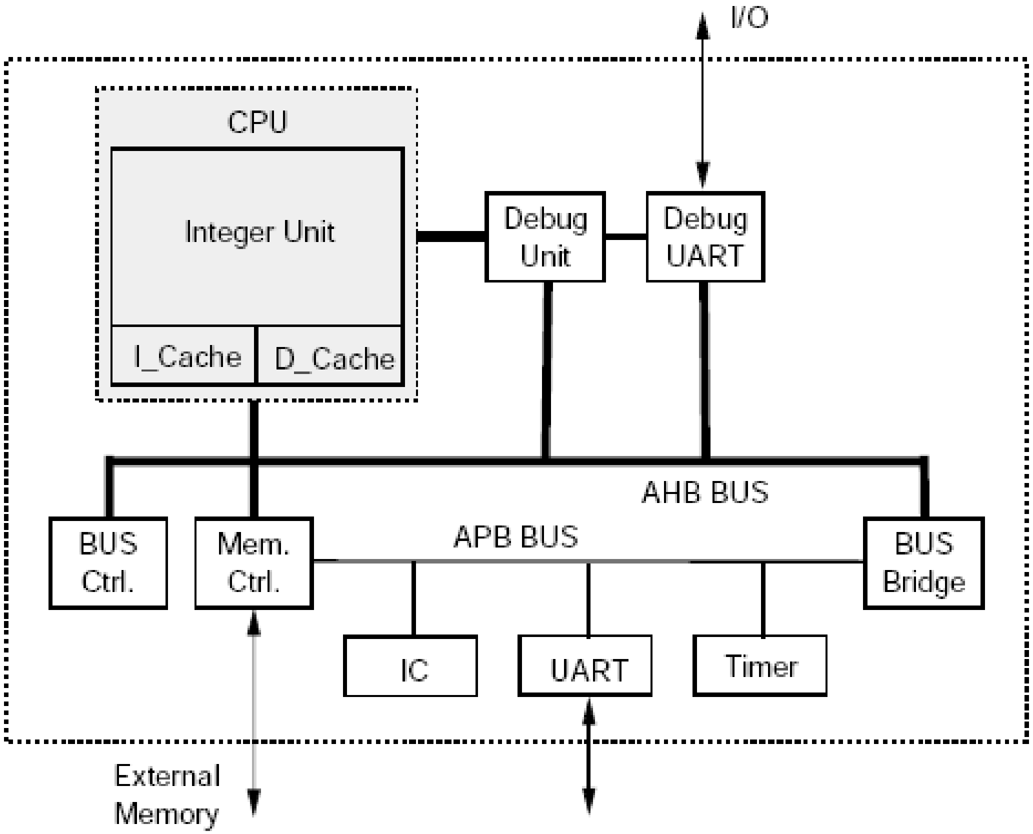
SoC Size: 8,302 LUTs

EPOS Size: 19,924 Bytes

Aspect Deployment



Tailored EPOS SoC



SoC Size: 10,428 LUTs

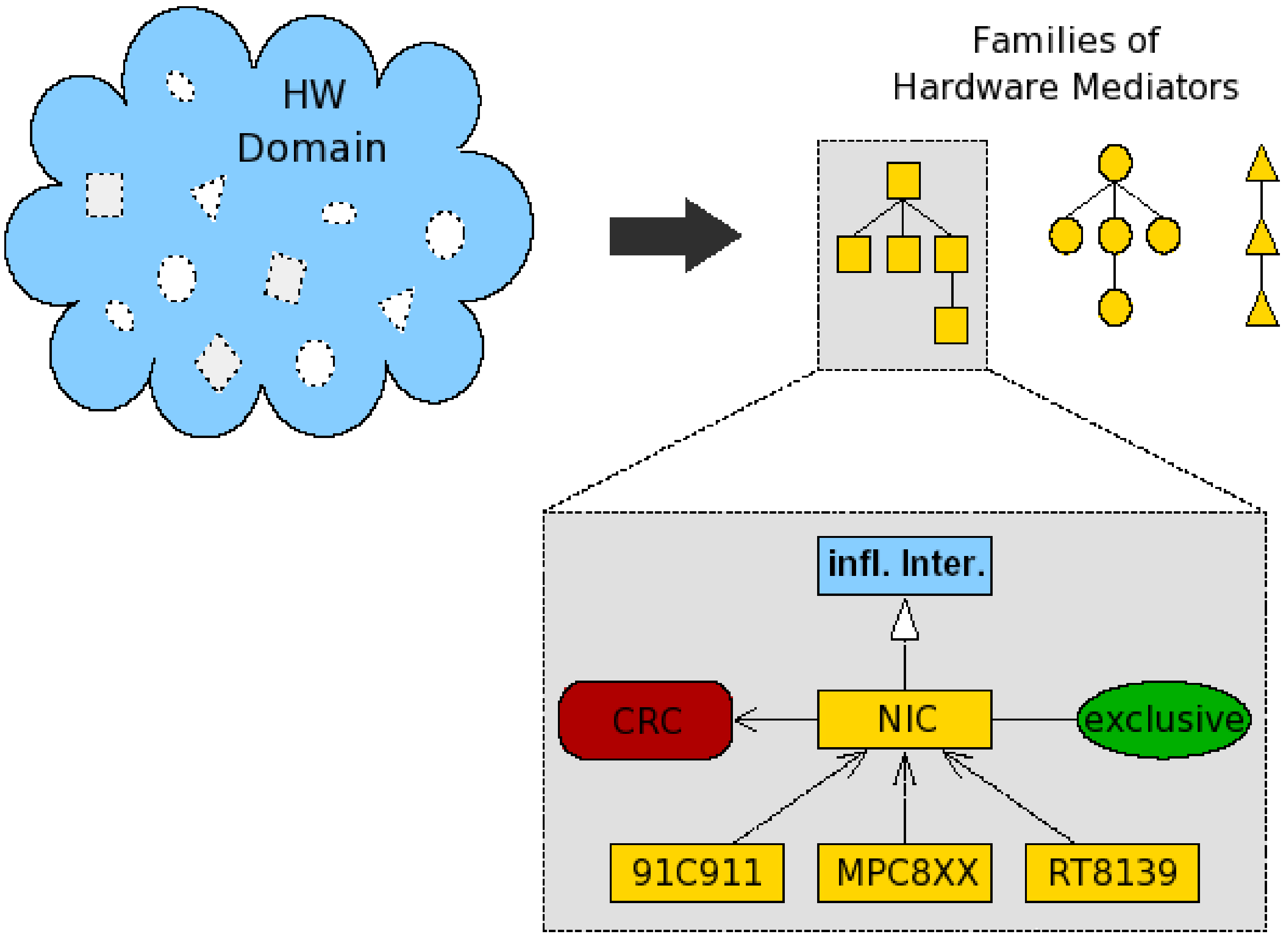
EPOS Size: 17,616 Bytes

Conclusions

- Hardware Soft IPs fit perfectly in EPOS
  - Described, selected and configured just like software components
- EPOS tools are now able to tailor a SoC
  - As long as the IPs have the proper design
  - A set of hardware mediators exists for the target machine
- Application-oriented SoC
  - Tools seem to be OK!
  - What about AOSD?
    - Develop our own soft-core processor (MIPS)
    - Aware of HDL restrictions (aspects, metaprograms, etc)

Ongoing Work

Hardware Mediators



OS

- Ordinary operating usually concerns on abstracting all the features that the platform provides
  - Absence of a component-based engineering
  - Useless of modern software engineering techniques
    - Increase design costs, NRE costs, time-to-market, ...
- SoCs call for operating system design methodologies