Type-Directed Compilation for Multicore Programming

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Concurrency at the Core(s) of Computing

- From monolithic Von Neumann architectures to multicore CPUs

  "multiple concurrent modules in a single application"

- A multicore CPU can be:
  - SMP (cache coherent): Intel, Niagara, ..
  - NUMA (non-cache coherent): MPSoC, Cell, ..

- DMA (Direct Memory Access) used in NUMA.

  ⟹ Issue: fast but *unwieldy* and *dangerous*

Target Machine Model (1)

- We assume the following simple machine model:
  - Consisting of multiple isomorphic VNMs (same ISA), each with local memory
  - Data sharing among cores through asynchronous writes between local memories (DMA, only the push-version in this talk)
- Close to the LogGP model in parallel computing
- Local memory size, OCIN topology, etc.: deliberately unspecified

Target Machine Model (2)

Why choose this model?

- Simple, efficient, general
- Close to many MPSoCs (including Cell)
- Harder to program than SMP — but is it true?

NB: *Other CMP issues deliberately ignored.*

Using Types for Interactions

- Session Types for high-level abstraction of conversation structures
- *First* specifies scenarios of conversations; *then* program and validate conformance
- Ensures communication/synchronisation safety (and other properties such as liveness)
- Can be a basis of other correctness arguments
- Can be a basis of efficient executions

A Type-Directed Compilation Framework

L2 Domain Specific Language (a la StreamFlex)

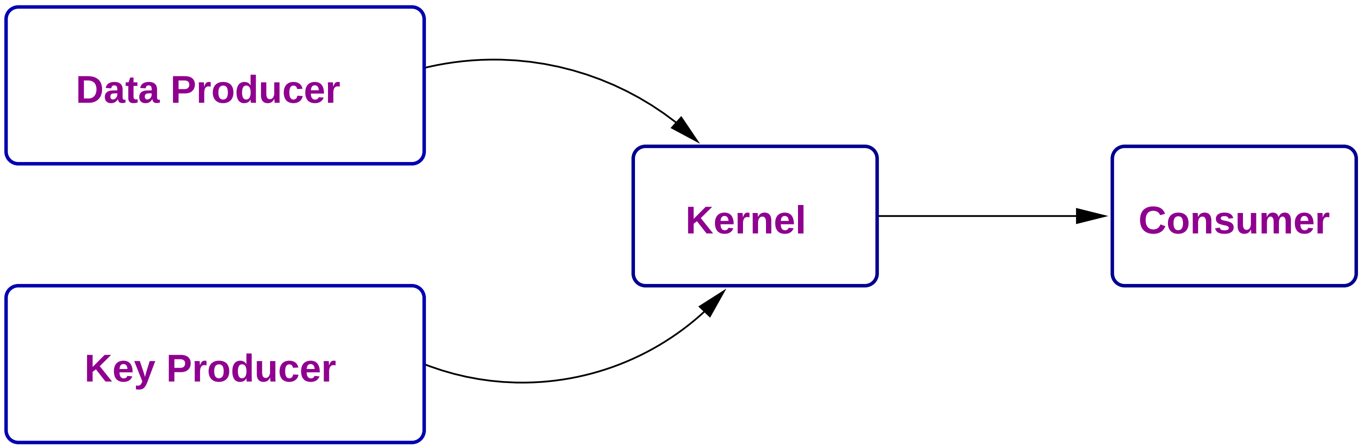
$\Downarrow$

L1 Applied π-Calculus with Session Types

$\Downarrow$

L0 Typed Assembly Language for CMP

L1: Streaming Example (1)



DataProducer

$$\text{def } \mathrm{P}(d, k, c) = d?();\ d!\langle data\rangle; \mathrm{P}\langle d, k, c\rangle \ \text{ in } \ a(d, k, c).\mathrm{P}\langle d, k, c\rangle$$

L1: Streaming Example (2)

Kernel

$$\text{def } \mathrm{K}(d, k, c)$$
$$= \; d!\langle\rangle;\; k!\langle\rangle;\; d?(x);\; k?(y);\; c?();\; c!\langle x \text{ xor } y\rangle;\; \mathrm{K}\langle d, k, c\rangle$$
$$\text{in } \; \overline{a}(d, k, c).\mathrm{K}\langle d, k, c\rangle$$

Types for Kernel

$$\mu\mathbf{t}.d!\,\langle\rangle; k!\,\langle\rangle; d?\,\langle\text{bool}\rangle; k?\,\langle\text{bool}\rangle; c?\,\langle\rangle; c!\,\langle\text{bool}\rangle; \mathbf{t}$$

Types for DataProducer

$$\mu\mathbf{t}.d?\,\langle\rangle; d!\,\langle\text{bool}\rangle; \mathbf{t}$$

L0: Streaming Example

```
main: {
  main: {
    r1 := getIdleCore
    r2 := getIdleCore
    r3 := getIdleCore
    r4 := getIdleCore
    fork dataProducer at r1
    fork keyProducer at r2
    fork kernel at r3
    fork consumer at r4
    yield
  }
}
```

```
dataProducer: {
  data: byte [128]
  ack: byte [0]
  main: {
    // produce data
    get ack
    put data in r3.data
    jump main
  }
}
```

L0: Streaming Example (1)

```
keyProducer: {
  key: byte [128]
  ack: byte [0]
  main: {
    // produce key
    get ack
    put key in r3.key
    jump main
  }
}
```

```
consumer: {
  buf: byte [128]
  ack: byte [0]
  main: {
    get buff
    // consume buf
    put ack in r3.ack
    jump main
  }
}
```

L0: Streaming Example (2)

```
kernel: {
  data: byte [128]
  key: byte [128]
  buf: byte [128]
  ackD: byte [0]
  ackK: byte [0]
  ackC: byte [0]
  main: {
    put ackD in r1.ack
    put ackK in r2.ack
    get data; get key
    r5 := 128; jump loop
  }
  loop: {
    when r5 < 0 jump done
    r6 := data[r4]; r7 := key[r4]
    buf[r4] := r7 xor r6;
    jump loop
  }
  done: {
    get ackS
    put sum in r1.arg
    jump main
  }
}
```

L0: Streaming Example (3)

A closer look at **get**:

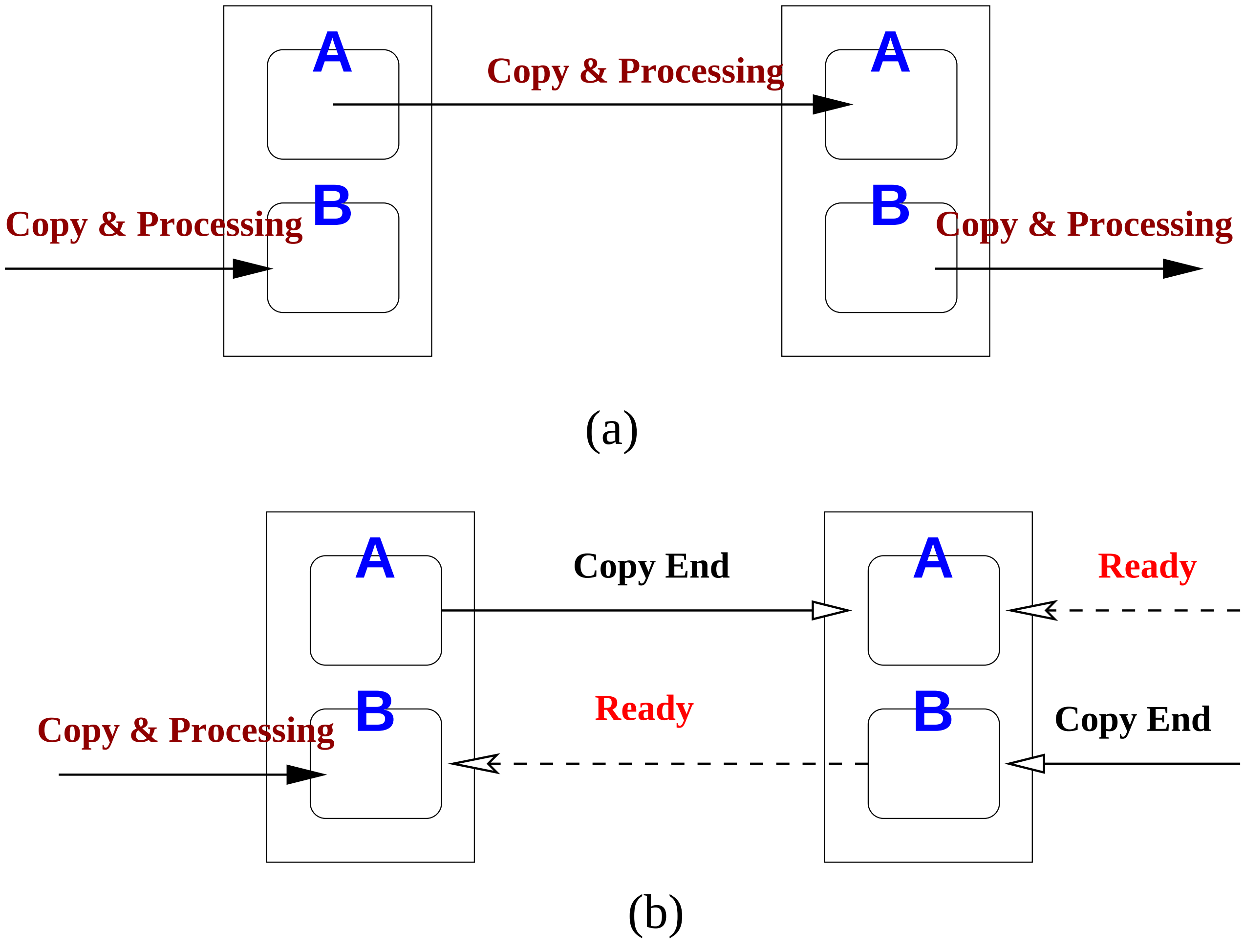
```
.....
get ack
.....
```

⟹

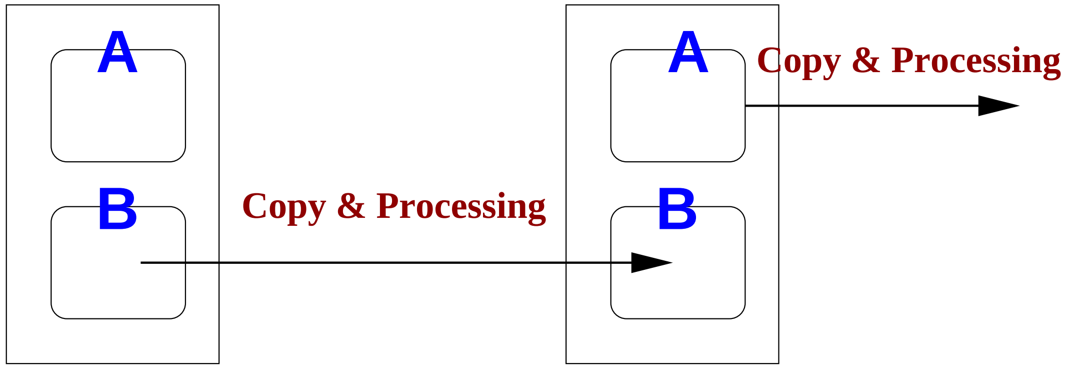
```
.....
__wait__ack: {
    when __received__ack jump done
    jump __wait__ack
}
done: {
    .....
}
```

where `__ack__received` is an implicit flag for `ack`, to be filled at the end of the corresponding **put**.

Double Buffering



Double Buffering



(c)

Types for Kernel

$$s \triangleleft \mathsf{ReadyA}; s \triangleleft \mathsf{ReadyB};$$

$$\mu \mathbf{t}.s?\,\langle T\rangle; k \triangleright \mathsf{ReadyA}; k!\,\langle T\rangle; s \triangleleft \mathsf{ReadyA}; s?\,\langle T\rangle;$$

$$k \triangleright \mathsf{ReadyB}; k!\,\langle T\rangle; \mathbf{t}$$

Related Works

- [Ennals et al 04; ...]: Thread-sensitive linear types for compiling packet processing to CMP.
- [Fahndrich et al 06; ...]: C# extended with a variant of session types for shared memory — for writing an OS.
- [Charles et al 05; ...]: Java extended with structured concurrent programming on PGAS — for HPC.
- [Spring et al 07]: JVM-based approach to fast stream programming.
- [Welch and Barnes 05]: A very fast CSP/π-based systems programming language.

Future Topics

- Can the framework really produce tight, fast code for a wide class of (stream) applications?
- Scalability to other application domains?
- Scalability to different HW configurations?
- Static (and dynamic) analyses for L1?
- Construction of performance models (cf. Log(G)P)
- Semantics, logic, ...