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)

⇓

L1 Applied $\pi$-Calculus with Session Types

⇓

L0 Typed Assembly Language for CMP
def P(d, k, c) = d?(); d!⟨data⟩; P⟨d, k, c⟩ in a(d, k, c).P⟨d, k, c⟩
def K(d, k, c)
    = d!⟨⟩; k!⟨⟩; d?(x); k?(y); c?(()); c!⟨x xor y⟩; K⟨d, k, c⟩
in a(d, k, c).K⟨d, k, c⟩

Types for Kernel

μt.d!⟨⟩; k!⟨⟩; d?⟨bool⟩; k?⟨bool⟩; c?⟨⟩; c!⟨bool⟩; t

Types for DataProducer

μt.d?⟨⟩; d!⟨bool⟩; t
L0: Streaming Example

```plaintext
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*:

\[
\begin{align*}
\text{......} \\
\_\_\text{wait}\_\_\text{ack}: \{ \\
\quad \text{when } \_\_\text{received}\_\_\text{ack} \quad \text{jump} \quad \text{done} \\
\quad \text{jump} \quad \_\_\text{wait}\_\_\text{ack} \\
\text{\} \\
\text{done}: \{ \\
\text{......} \\
\text{\} }
\end{align*}
\]

where \_\_\text{ack} \_\_\text{received} is an implicit flag for \text{ack}, to be filled at the end of the corresponding \text{put}. 
Double Buffering

(a)

(b)
Double Buffering

Types for Kernel

\[ s \triangleright \text{ReadyA}; s \triangleright \text{ReadyB}; \]
\[ \mu t.\ s? \langle T \rangle; k \triangleright \text{ReadyA}; k! \langle T \rangle; s \triangleright \text{ReadyA}; s? \langle T \rangle; \]
\[ k \triangleright \text{ReadyB}; k! \langle T \rangle; t \]
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, ...