CASM - Optimized Compilation of Abstract State Machines [1]

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Abstract State Machines

ASM in a nutshell:

- well-founded (formal) method
- generalization of finite state machines
- changes *interpretation* of an *algebra*

pure functions calculate successor state in parallel

ASM is well suited for:

- programming language semantics
- **clocked circuits (like micro-processors)**

Motivation

We use ASM in:

- compiler verification
- formalization of instruction sets

```
rule addiu(addr : Int) =
  let rs = FIELD(addr, FV_RS) in
  let rt = FIELD(addr, FV_RT) in
  let imm= FIELD(addr, FV_IMM) in
    if rt != 0 then
      GRP(rt) := BVadd(32, GPR(rs), BVse(16, 32, imm))
```

MIPS *addiu* (functional model)

Idea: re-use models for

- instruction set simulation (ISS)
- compiled simulation (CS)

Issue: existing ASM tools too slow ⇒ **CASM**

- statically typed
- compilation to C

Parallel and Sequential execution semantics

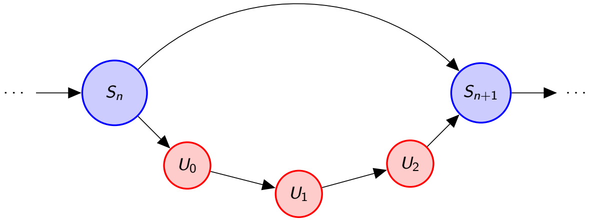
Swap

```
{
        x  :=  y
        y  :=  x
}
```

parallel semantics

```
{|
        t  :=  x
        x  :=  y
        y  :=  t
|}
```

sequential semantics



$\Rightarrow$ concise modeling parallelism in pipelines / VLIW

PAR/SEQ nesting

program

```
{
| {|
| | x := 23
| | y := 42
| | {
| | |    x := y
| | |    y := x
| | }
| |}
| // ...
```

updates	state	update-set
	x=undef, y=undef	{}
x=23	x=23, y=undef	{ x_1=23 }
y=42	x=23, y=42	{ x_1=23, y_1=42 }
x=42		{ x_2=42, y_1=42 }
y=23		{ x_2=42, y_2=23 }
	x=42, y=23	
	x=undef, y=undef	{ x_1=42, y_1=23 }

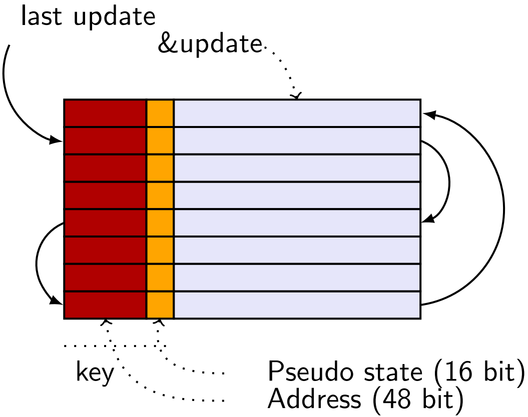
- sequential execution of parallel blocks
- updates collected into sets
- on leaving a block: merge updates into surrounding one

Idea: no intermediate states, *overlay* update-set

- run-time stack of update-sets

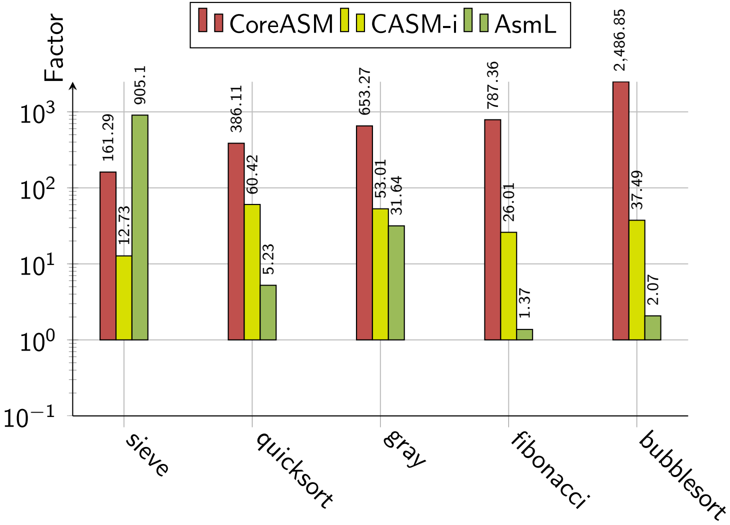
Linked Hash-Map

lookup: $\mathcal{O}(\#ps)$, merge: $\mathcal{O}(\#updates)$, insert: $\mathcal{O}(1)$



⇒ most expensive run-time operations

CASM baseline compiler



Redundant Lookup and its Elimination

```
{

  if X(3) = 3 then
    skip
  if X(3) = 4 then
    skip
}
```

```
{
  local X_3 = X(3) in
    if X_3 = 3 then
      skip
    if X_3 = 4 then
      skip
}
```

Optimization Patterns 2/3

Preceded Lookup and its Elimination

```
{|
  X(4) := foo
  if X(4) > 0 then
    skip
|}
```

```
local L_1 = foo in
  {|
    X(4) := L_1
    if L_1 > 0 then
      skip
  |}
```

Optimization Patterns 3/3

Redundant Update and its Elimination

```
{|
  X(5) := foo
  X(5) := bar
|}
```

```
{|

  X(5) := bar
|}
```

Patterns in Compiled Simulation (simplified)

```
rule basicblock = {|
  call fetch(0x8000)
  call execute
  call step

  call fetch(0x8001)
  call execute
  call step

  // ...

  call fetch(0x8023)
  call execute
  call step
|}
```

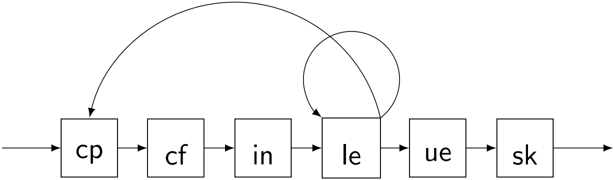
- redundant update
- preceded lookup
- redundant lookups

```
//pipeline stages
enum S = { S1, S2, S3 }

// phases (latch-in, latch-out)
enum P = { P1, P2 }

rule fetch(r : Int) =
  pipeline(S1) := PROGMEM(r)

rule execute =
  forall s in S do
    if pipeline(s) != undef then {|
          call (pipeline(s))(P1)
          call (pipeline(s))(P2)
    |}

rule step = {
  pipeline(S2) := pipeline(S1)
  pipeline(S3) := pipeline(S2)
}
```

similar for register file

Supporting Optimizations

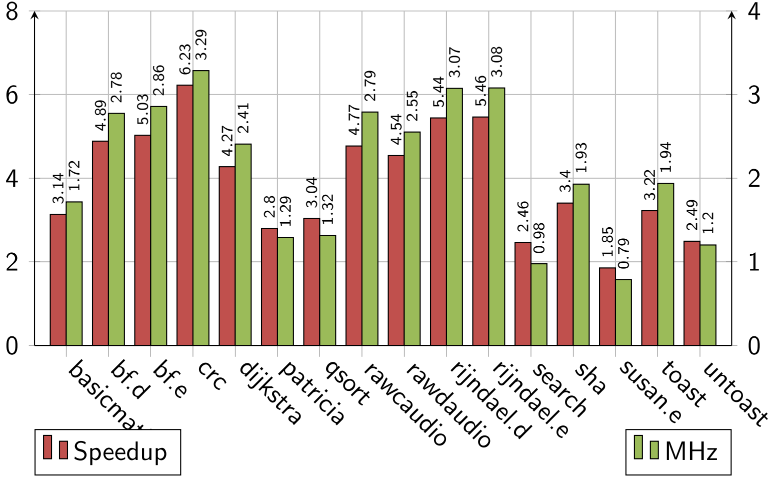
Key: statical analysis of *locations*



- constant propagation
- constant folding
- inlining
- lookup elimination
- update elimination
- sinking

compilation to C ⇒ less complex code, better C optimization

Achieved Speedup and Performance



speedup depends on size of frequently executed basic blocks

Conclusion

- re-use of formal models
- baseline compiler order of magnitudes faster than other tools
- for CS application: optimizations yield factor 6
- current work: interprocedural analysis, new optimziations