Approximate Computing with Runtime Code Generation on Resource-Constrained Embedded Devices

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Damien Couroussé Caroline Quéva Henri-Pierre Charles

Univ. Grenoble Alpes, F-38000 Grenoble, France
CEA-LIST, MINATEC Campus, F-38054 Grenoble, France

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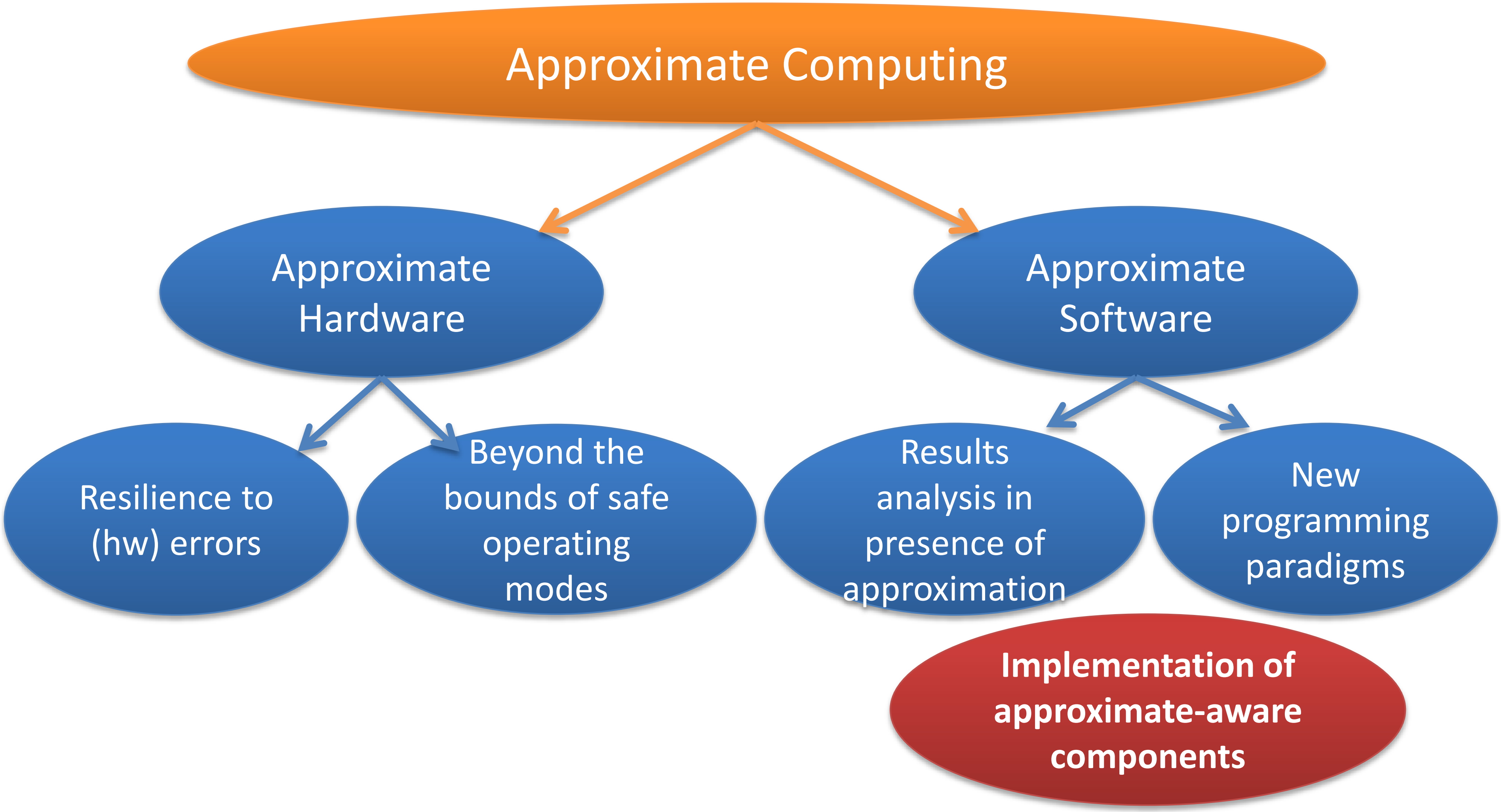
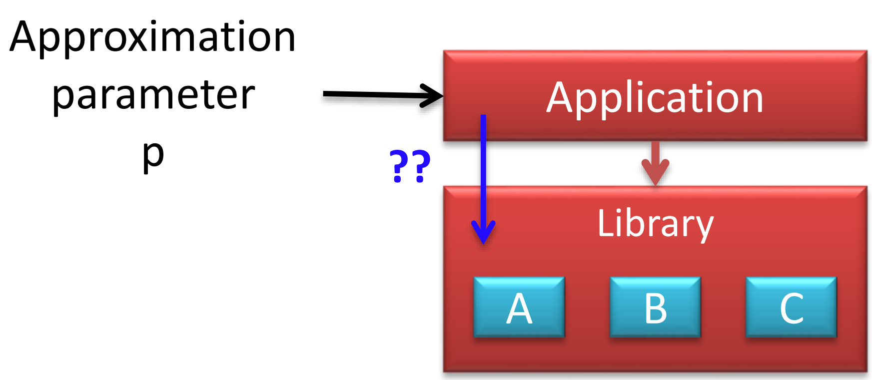
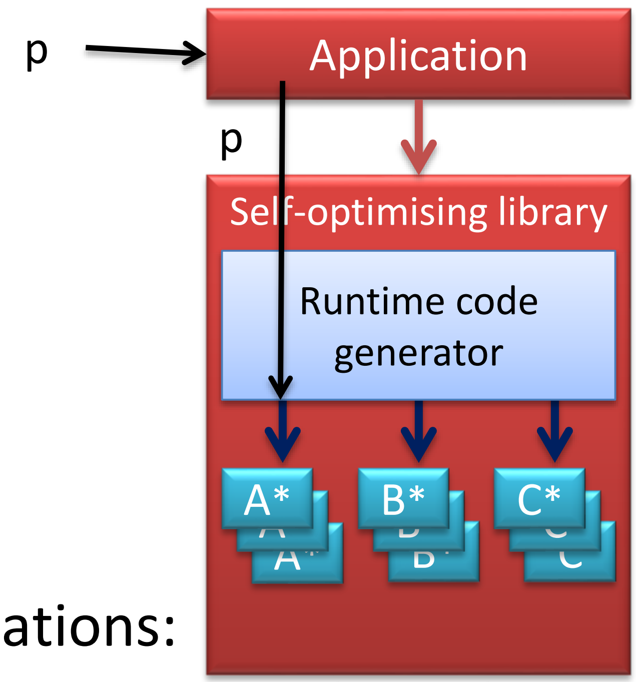
an approximate overview of







Solutions for precision-aware implementations:

- Generic implementation over every possible value of p
  - Easy to implement. Not efficient
- Static versionning
  - Almost zero runtime overhead. Big memory consumption
- Runtime code generation
  - Extra overhead for runtime code generation. Memory lightweight. Greater flexibility

runtime code generation with deGoal

Pitch: some code optimisations are not accessible to static compilers

- Unknown data
- Sometimes, the hardware is also unknown, at least partially

- Delay code optimisations at runtime
  - Constant propagation, elimination of dead code,
  - Strength reduction,
  - Loop unrolling,
  - *Instruction scheduling,*
  - etc.
- Drive code performance by runtime-changing constraints
  - Bounds : power / energy / execution time
  - Heterogeneous cores : accelerators, specialized instructions

deGoal

- Portable DSL
- Complex variables (registers): vector support, dynamically sized, typed
- Mix runtime data & binary code
- Extendable to domain-specific instructions

Results

- Auto-adaptative dynamic libraries
- Portable runtime optimization
- Multiple performance metrics:
  - Generated code is smaller and faster
  - Code generators are smaller and faster

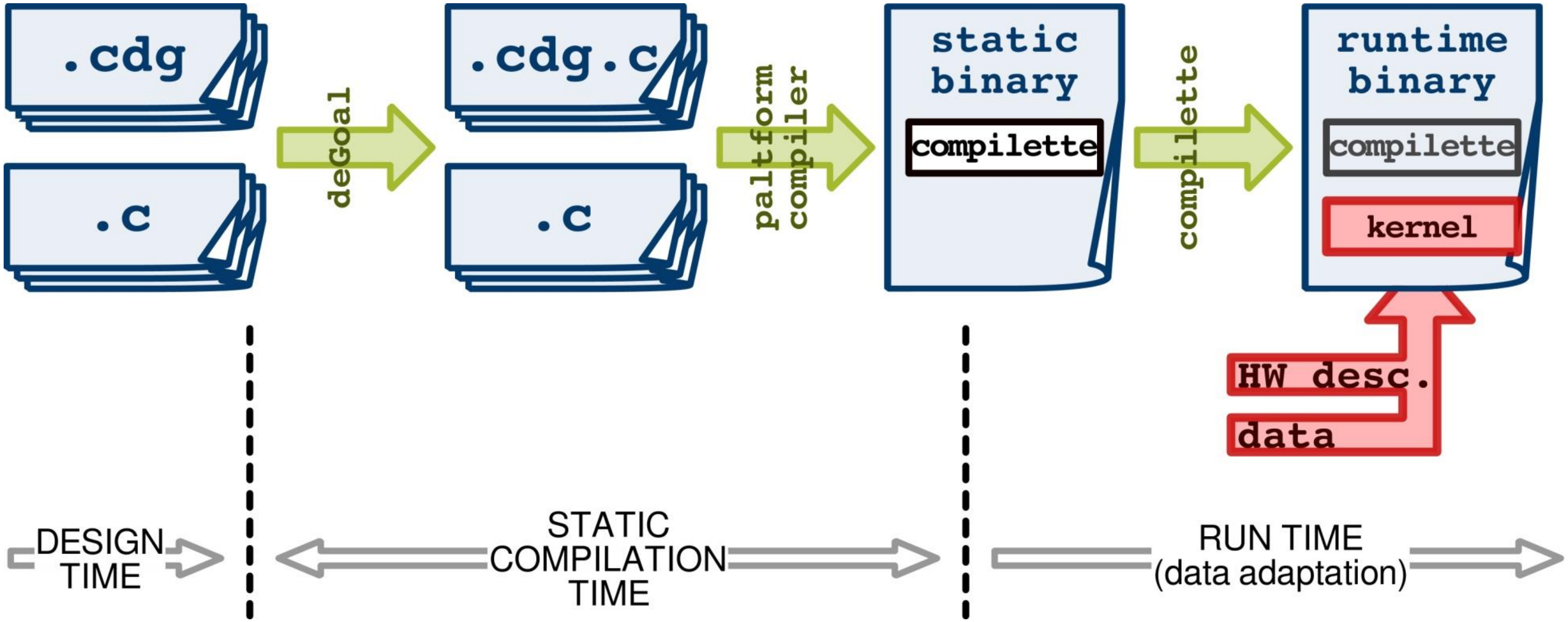
Simple program example: vector addition

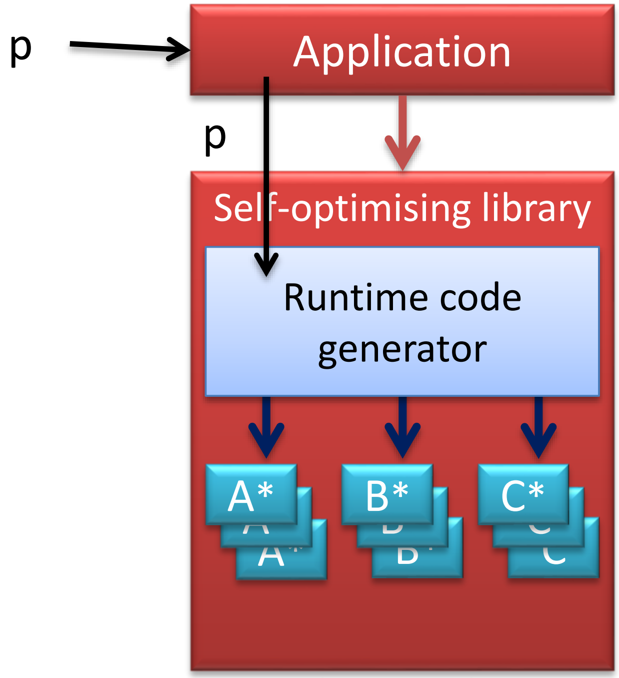
```
void gen_vector_add(void *buffer, int vec_len, int val)
{
#[
    Begin buffer Prelude vec_addr
    Type int_t int 32 #(vec_len)
    Alloc int_t v

    lw v, vec_addr
    add v, v, #(val)
    sw vec_addr, v
]#
}
```

Program memory:

```
ldr r1, [r0]
add r1, #1
str r1, [r0]
add r0, #4
ldr r2, [r0]
add r2, #1
str r2, [r0]
add r0, #4
```

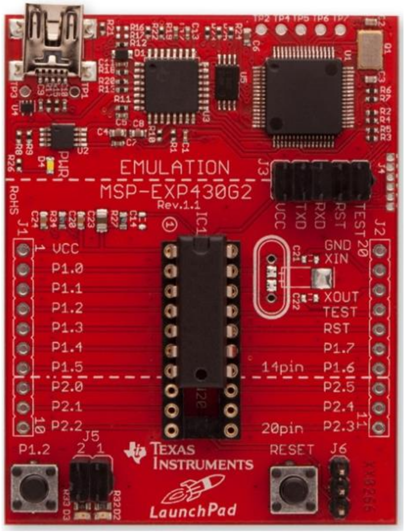
code generation flow




p
Application
p
Self-optimising library
Runtime code generator
A*
B*
C*

use case: floating point multiplication

- MSP430: 512 bytes of RAM only!
- Floating-point multiplications on MSP430
  - Standard library function : ~1000 cycles per invocation
  - Micro-controllers lack dedicated HW support for arithmetic computing
  - Linear function often used to convert sensor value to user value
- Approximation of precision p using mantissa truncation



t_{ref} : execution time of libm's multiplication routine

t_{gen} : execution time of code generation

t_{approx} : execution time of the generated approximate function

- speedup :

$$s = \frac{t_{approx.}}{t_{ref}}$$

- overhead recovering :

$$N = \frac{t_{gen}}{t_{ref} - t_{approx}}$$

Precision-aware implementation,

no data specialisation

reference version

```
float fmul (float M, float X)
{
    return (M*X);
}
```

approximate version

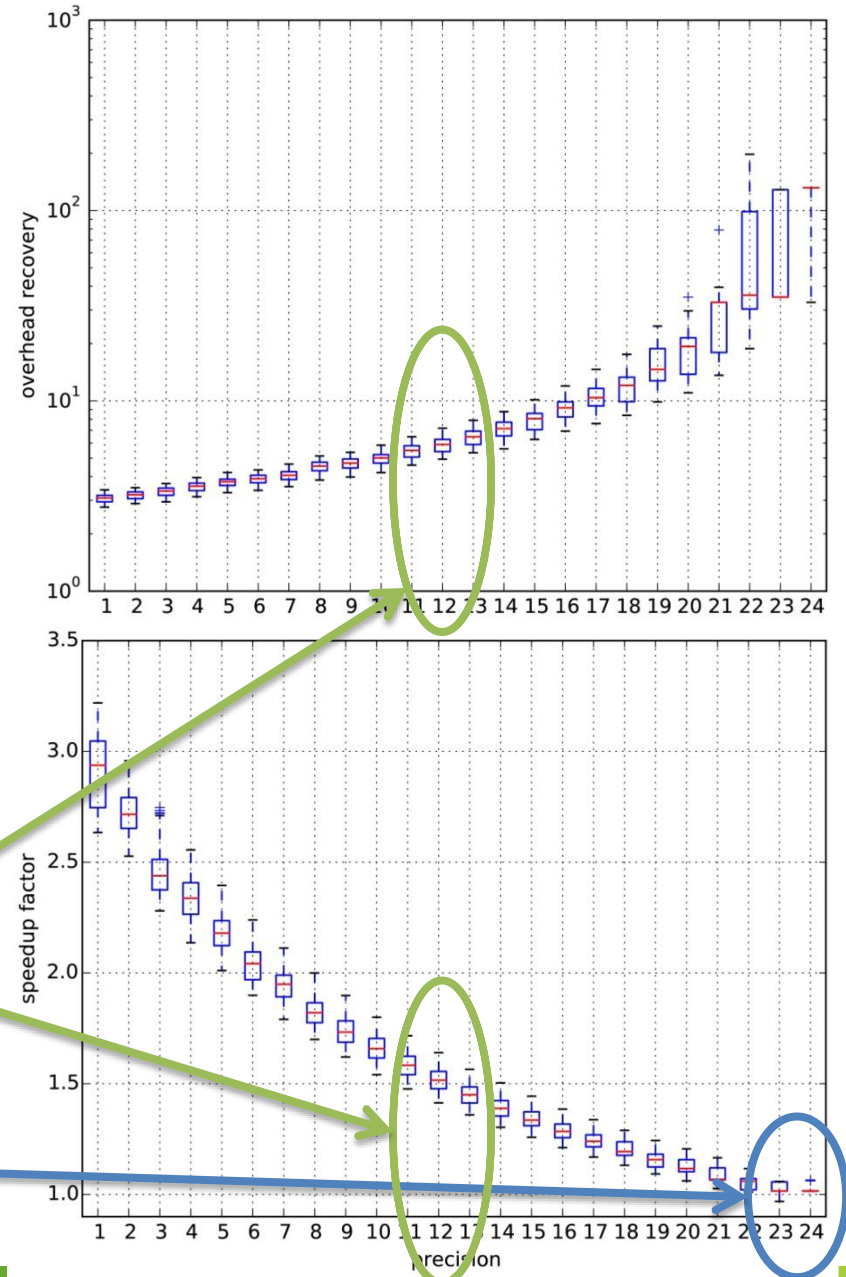
```
set_precision(p); /* p in [1;24] */
float fmul (float M, float X)
{
    return (M*X);
}
```

results #1

Precision-aware implementation, no data specialisation

- Reference implementation: libm for msp430
- Our generated implementation:

  Precision p in [1; 24]



p=12, speedup ~ x1,5
overhead recovery ~ 8

p=24, (similar to libm)
no performance improvement,
high overhead recovery

Precision-aware implementation, with data specialisation

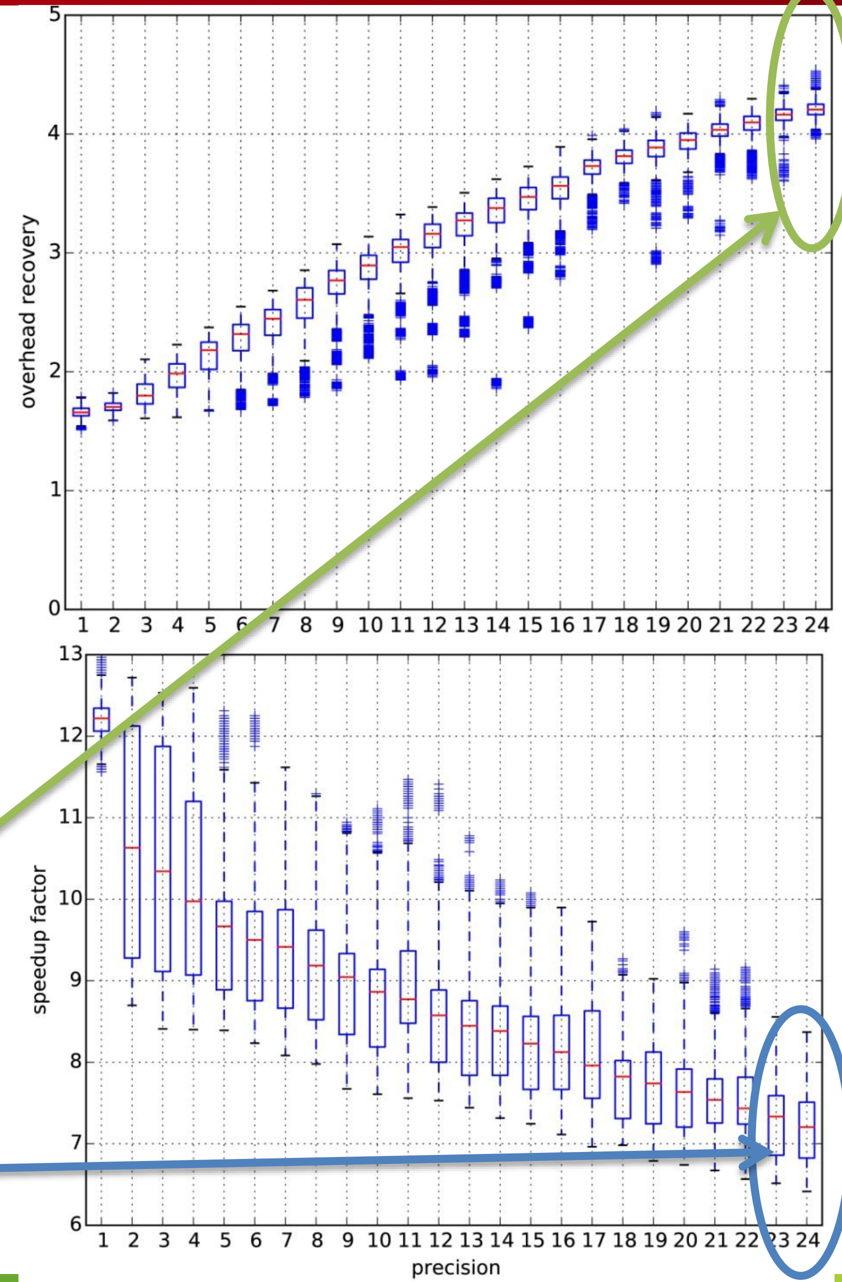
```
set_precision(p); /* p in [1;24] */
f = compile_fmul(M);
float fmul (float M, float X)
{
    return f(X);   /* return M*X */
}
```

Precision-aware implementation, with data specialisation

- Reference implementation: libm for msp430
- Our generated implementation:
  Precision p in [1; 24]

<5 executions only to pay off code generation in the worst case

p=24, (similar to libm)
Speedup > 6x,
> 7x 80% of the time



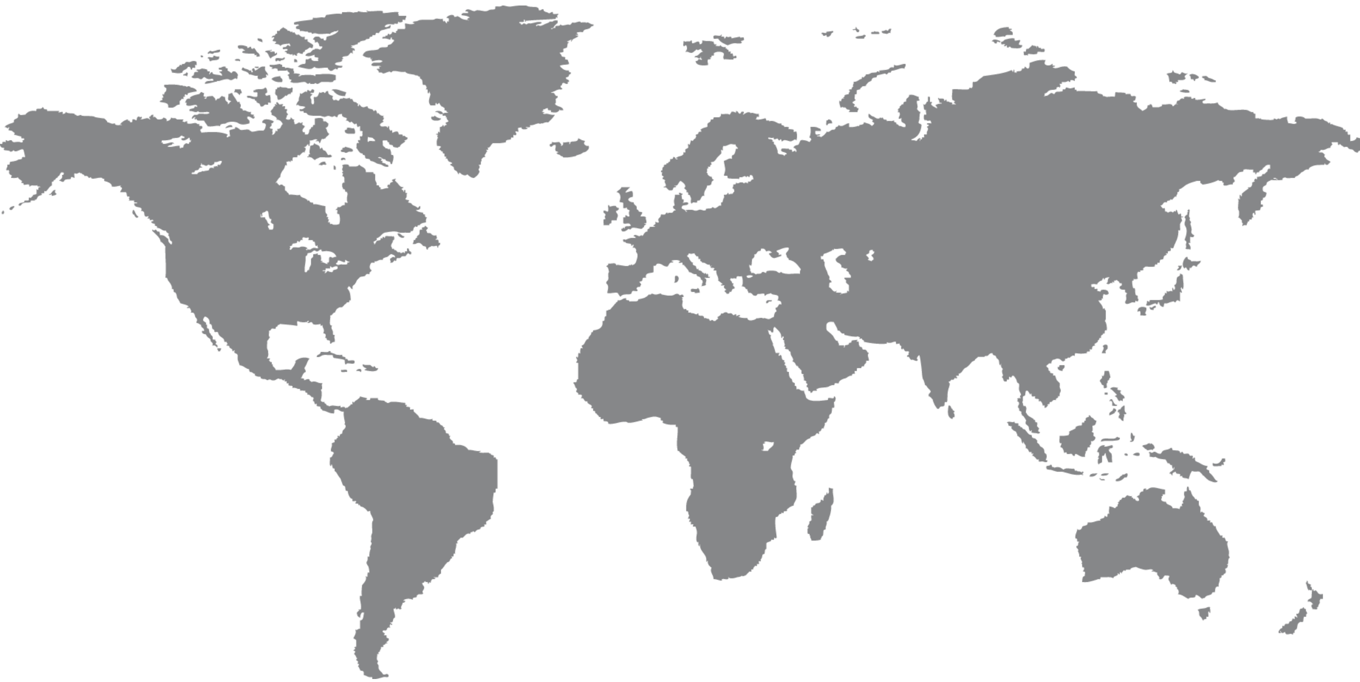
conclusion

- Provide the average developer with approximate-aware components
- Runtime code specialisation for approximate-aware applications
- > 7x faster with data specialisation in our use case
  - Approximation can improve the speedup up to 10x
- Follow-up work: drive code generation by higher level tools for approximation analysis

!! ??

Approximate Computing on Resource-Constrained Embedded Devices with Runtime Code Generation

damien.courousse@cea.fr



INSTITUT CARNOT CEA LETI

INSTITUT CARNOT CEA LIST

MINATEC®

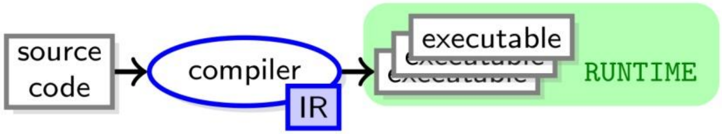
digiteo

leti
Centre de Grenoble
17 rue des Martyrs
38054 Grenoble Cedex

list
Centre de Saclay
Nano-Innov PC 172
91191 Gif sur Yvette Cedex

Approaches for code specialization

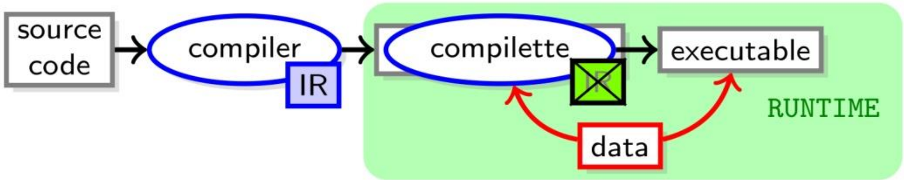
Static code versionning (e.g. C++ Templates)



- static compilation
- runtime: select executable
- memory footprint ++
- limited genericity
- runtime blindness

Runtime code generation, with `deGoal`

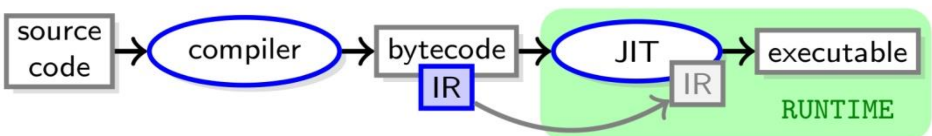
A *compilette* is an ad hoc code generator, targeting one executable



- fast code generation
- memory footprint −−
- **data-driven code generation**

Dynamic compilation

(JITs, e.g. Java Hotspot)



- overhead ++
- memory footprint ++
- not designed for data dependant code-optimisations

IR Intermediate Representation

deGoal supported architectures

ARCHITECTURE	STATUS	FEATURES
ARM32	✓	
ARM Cortex-A, Cortex-M [Thumb-2, VFP, NEON]	✓	SIMD, [IO/OoO]
STxP70 [including FPx] (STHORM / P2012)	✓	SIMD, VLIW (2-way)
K1 (Kalray MPPA)	✓	SIMD, VLIW (5-way)
PTX (Nvidia GPUs)	✓	
MIPS	↺	32-bits
MSP430 (TI microcontroler)	✓	Up to < 1kB RAM
CROSS CODE GENERATION supported (e.g. generate code for STxP70 from an ARM Cortex-A)		

[IO/OoO]: Instruction scheduling for in-order and out-of-order cores