Advances in Dynamic Compilation for Functional Data Parallel Array Processing

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What is ...

Functional Data Parallel Array Processing ?

- Programming with multidimensional, immutable arrays
- Abstract from structural properties of arrays
- Treat arrays as abstract values
- Storage, layout, operations, ... all implicit

Single Assignment C (SAC)

Language:

- Purely functional programming language
- Generic data-parallel array processing
- All arrays immutable
- Syntax imitates ISO C
    - Assignment sequences (→ let-expressions)
    - Branches (→ conditional expressions)
    - Loops (→ tail-recursive functions)

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Compiler:

- Highly optimising compiler
- Performance competitive with Fortran or C
- Automatic parallelisation for
  - Symmetric multicore multiprocessors
  - Graphics accelerators
  - Heterogeneous systems

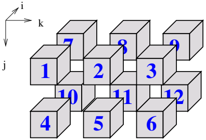
Multidimensional Array Calculus: Rank and Shape

[1, 2, 3, 4, 5, 6]

rank: 1
shape: [6]

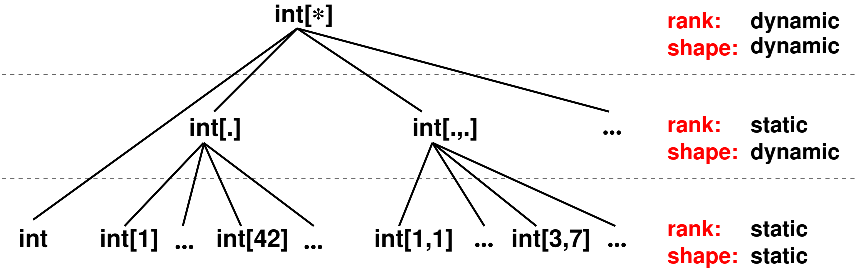
$$\begin{pmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{pmatrix}$$

rank: 2
shape: [3,3]

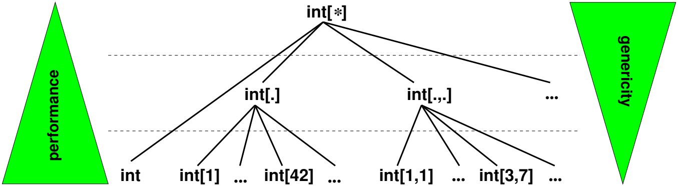


rank: 3
shape: [2,2,3]

Shapely Array Type Hierarchy



Genericity vs Performance Trade-Off



What software engineering principles demand:

- rank- and shpahe-generic programs
- wide-spread applicability
- code reuse

What the machine needs for performance:

- code customised to processed data
- exploit compile time knowledge for optimisation
- overcome abstraction boundaries

How Can We Reconcile Genericity and Performance ?

Observation:

- Often small numbers of different shapes prevail.
- Specialisation for concrete ranks and shapes !!
- Effectively apply large-scale static optimisation !!

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Solution:

Dynamic Compilation to the rescue !

Solution: Adaptive Runtime Specialisation

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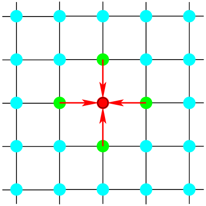
Idea:

- Set one core aside for dynamic code adaptation
- Incrementally generate more efficient code as shape information becomes available
- Accumulate adapted code in running process through dynamic linking
- Use adapted code as soon as available through dynamic dispatch

Case Study: Convolution with Convergence Check

Algorithmic principle:

Iteratively compute the weighted sums of neighbouring elements with cyclic neighbourhoods and dynamic convergence check

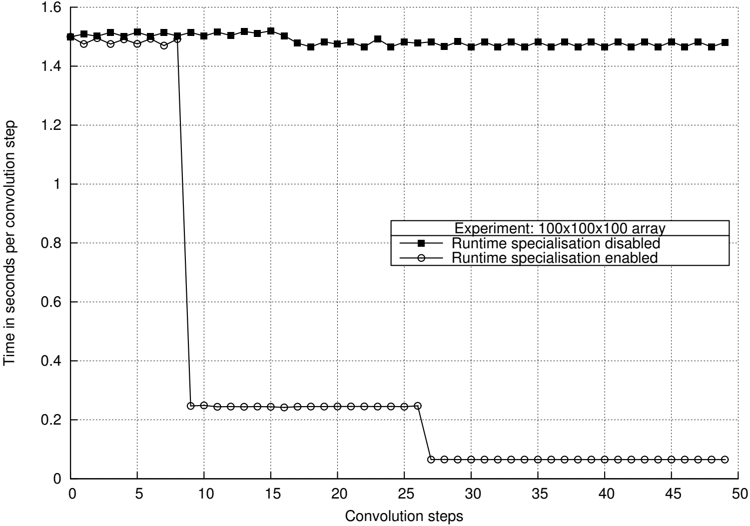


Implementation in SAC:

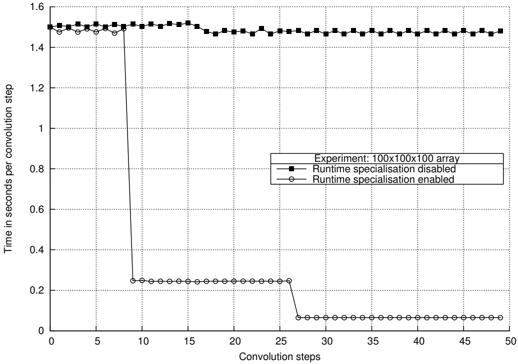
```
double[*] convolution (double[*] A, double eps)
{
  do {
    A_old = A;
    A = convolution_step( A_old);
  }
  while (!is_convergent( A, A_old, eps));

  return A;
}
```

Evaluation Example: 3-d Convolution 100x100x100



Availability of Adapted Code



Key question:

How can we speed up the availability of adapted code ?

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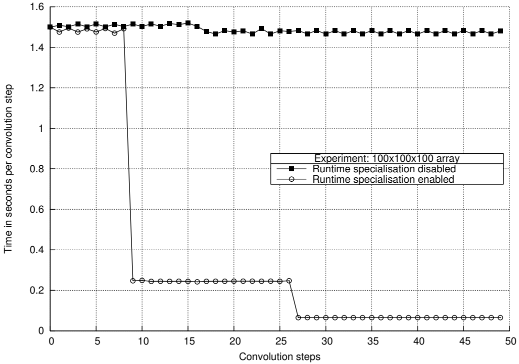

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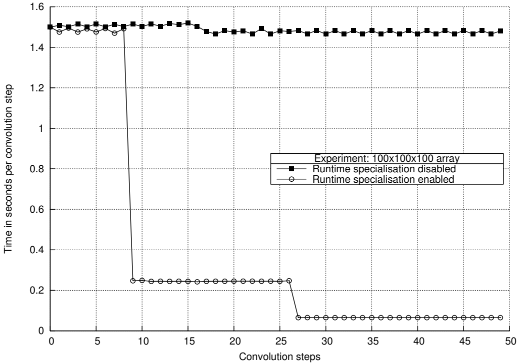

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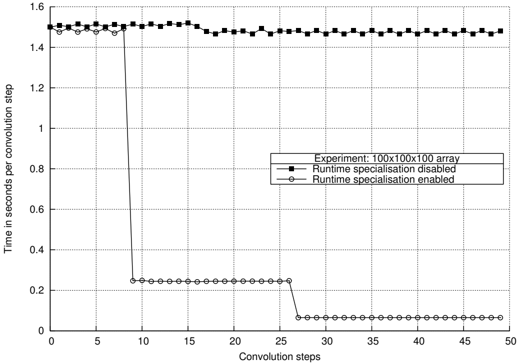

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Subject of this talk: 4 complementary proposals to speed up availability of adapted code

Idea 1: **Manifold** Asynchronous Adaptive Specialisation

Key observations:

- Specialisation requests come in in bursts
- Dynamic specialisation often exhibits a great deal of sharing among functions from same module
- Specialising two functions in conjunction may take the same time as each individually

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- Specialisation requests come in in bursts
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Our solution:

- Postpone triggering a specialisation by some (small) amount of time
- Expect more specialisation requests before cut-off time
- Specialise multiple functions together

Idea 2: **Prioritised** Asynchronous Adaptive Specialisation

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- Different specialisations yield different performance improvements
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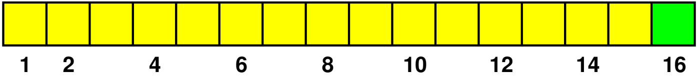
Solution:

- Turn specialisation request queue into priority queue
- Create buckets of functions from same module
- Gather statistical profiling data regarding effectiveness of specialisation

Idea 3: **Parallel** Asynchronous Adaptive Specialisation

First approach: dedicated specialisation core:



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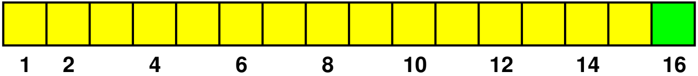

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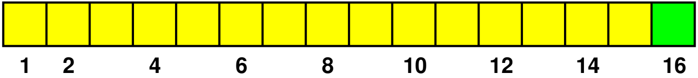

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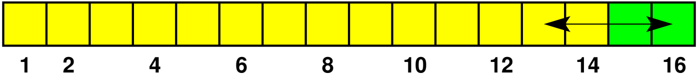
Solution:

- Dynamically adjust number of specialisation cores:



Idea 4: **Persistent** Asynchronous Adaptive Specialisation

Key observations:

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Solution:

- Store dynamic specialisations in installation-wide persistent storage
- Incrementally update the binary format of a module with new specialisations as they materialise
- Use replacement policies as in cache memories (e.g. least recently used)
- Learn which shapes are relevant.

Conclusion and Future Work

Conclusion:

- **Time to availability of specialisations is crucial !**
- We propose 4 complementary measures:
  - Manifold .....
  - Prioritised .....
  - Parallel .....
  - Persistent .....

..... asynchronous adaptive specialisation

Future work:

- Complete implementation(s)
- Conduct more case studies
- Do extensive evaluation
- Give a talk at DCE 2015