Towards Persistent and Parallel Asynchronous Adaptive Specialisation for Generic Data-Parallel Array Processing in SAC

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Universiteit van Amsterdam

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What is Generic Array Processing ?

- Programming with multidimensional 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
- Syntax imitates ISO C
  - Assignment sequences
  - Branches
  - Loops
- Semantics as expected by naive (imperative) programmer

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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

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

dim:	2
shape:	[3,3]
data:	[1,2,3,4,5,6,7,8,9]

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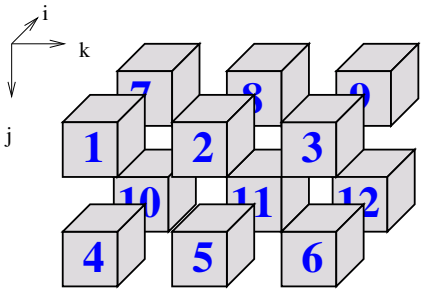

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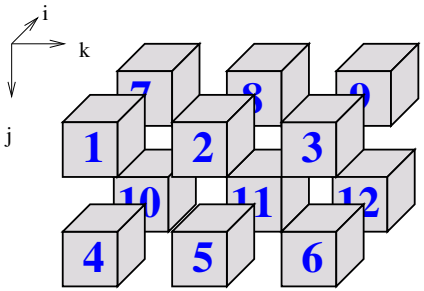

dim: 3
shape: [2,2,3]
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[1, 2, 3, 4, 5, 6]

dim: 1
shape: [6]
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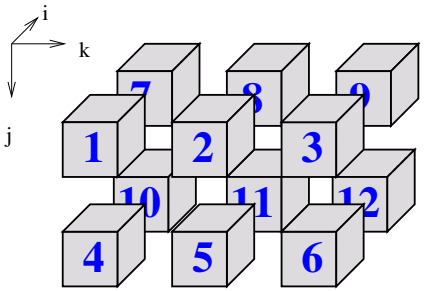

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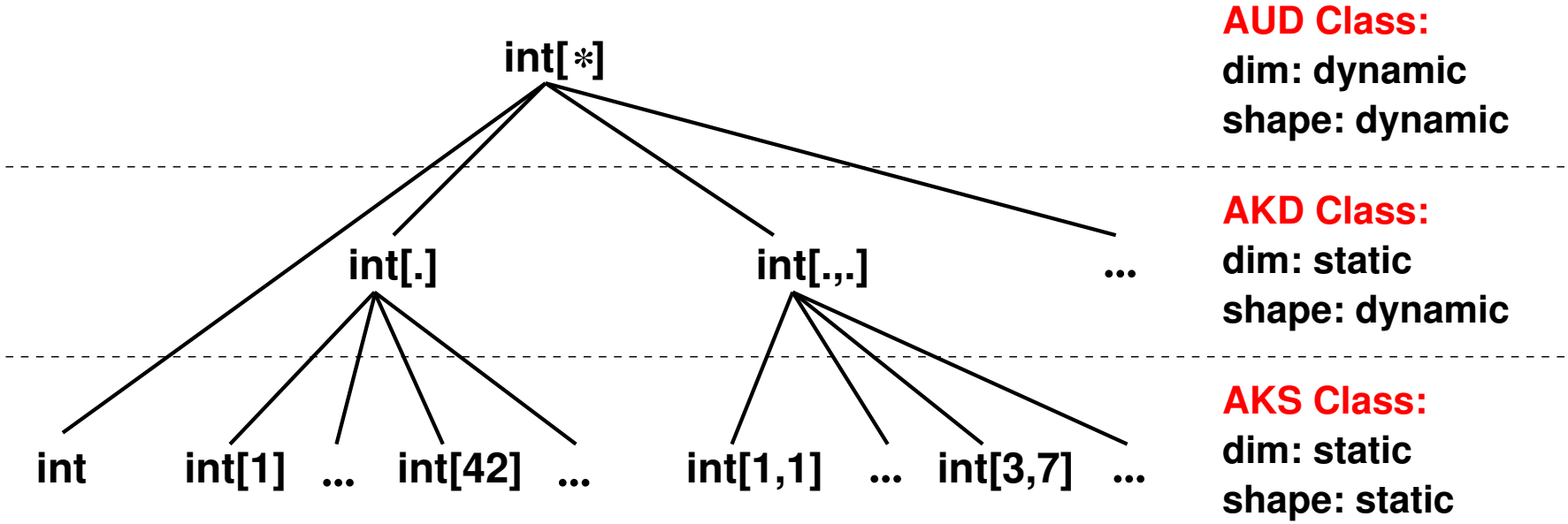
dim: 1
shape: [6]
data: [1,2,3,4,5,6]

42

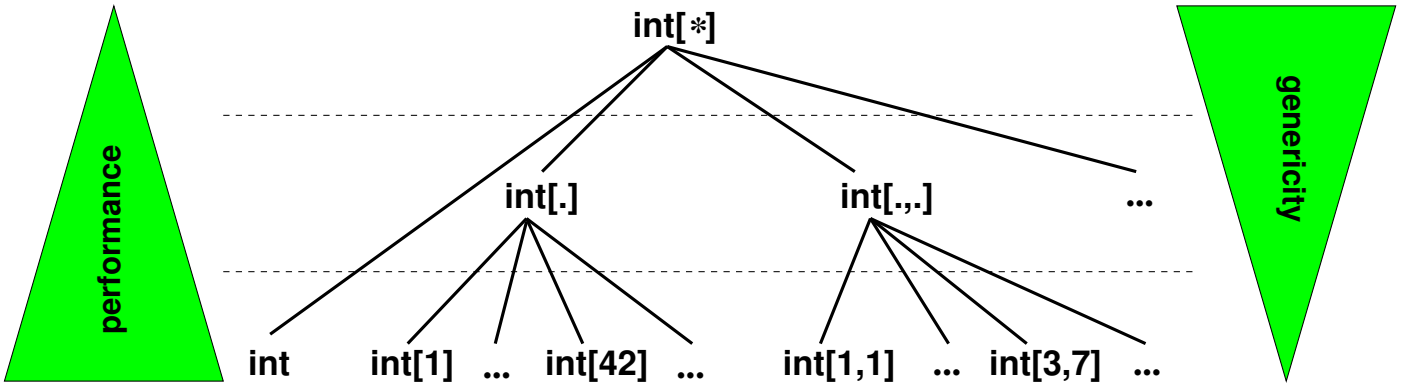
dim: 0
shape: [ ]
data: [42]

Shapely Array Type Hierarchy



AUD : Array of Unknown Dimension
AKD : Array of Known Dimension
AKS : Array of Known Shape

Genericity vs Performance Trade-Off



What software engineering principles demand:

- generic programs
- wide-spread, uniform applicability
- abstraction and composition

What the machine needs for performance:

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

Why is generic code less efficient ?

Runtime representation of data:

- Rank and or shape vector need to be maintained dynamically
- More memory management, more function parameters, etc.

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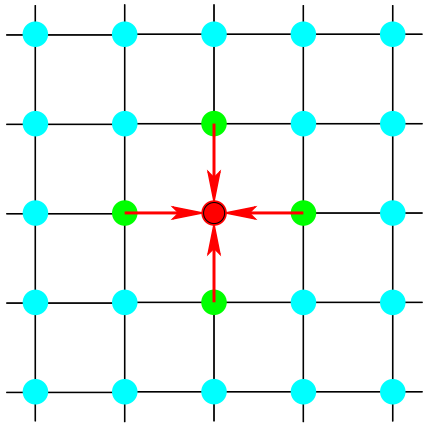
Effectiveness of optimisation:

- SAC promotes a (very) compositional programming style
- Despite C-like syntax: abstraction, abstraction, abstraction
- For performance: resolve abstractions through optimisation

Case Study: Convolution with Cyclic Boundary Conditions

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;
}
```

Convolution in SAC

Convergence criterion:

```
bool
is_convergent (double[*] new, double[*] old, double eps)
{
  return all( abs( new - old) < eps);
}
```

Convolution step:

```
double[*] convolution_step (double[*] A)
{
  R = A;
  for (i=0; i<dim(A); i++) {
    R = R + rotate( i, 1, A) + rotate( i, -1, A);
  }
  return R / tod( 2 * dim(A) + 1);
}
```

Rotation from the SAC Standard Library

```
double[+] rotate (int dimension, int count, double[+] A)
{
  if (count == 0) {
    result = A;
  }
  else {
    max_rotate = shape(A)[dimension];
    if( max_rotate == 0) {
      result = A;
    }
    else {
      count = count % max_rotate;
      if (count < 0) {
        count = count + max_rotate;
      }

      offset = 0 * shape(A);
      offset[dimension] = count;

      slice_shp = shape(A);
      slice_shp[dimension] = count;

      result = with {
                 ( offset <= iv <= . ) : A[iv-offset];
               } : modarray( A );

      result = with {
                 ( . <= iv < slice_shp ) : A[shape(A)-slice_shp+iv];
               } : modarray( result );
    }
  }
  return result;
}
```

How Can We Reconcile Genericity and Performance ?

Observation:

- Often small numbers of different shapes prevail.
- Specialisation !!
- Large-scale static optimisation !!

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Limitations:

- Code obfuscation
- Arrays obtained from external source (e.g. file)
- Functions called from external environment (e.g. C code)

Solution: Adaptive Runtime Specialisation

Observations:

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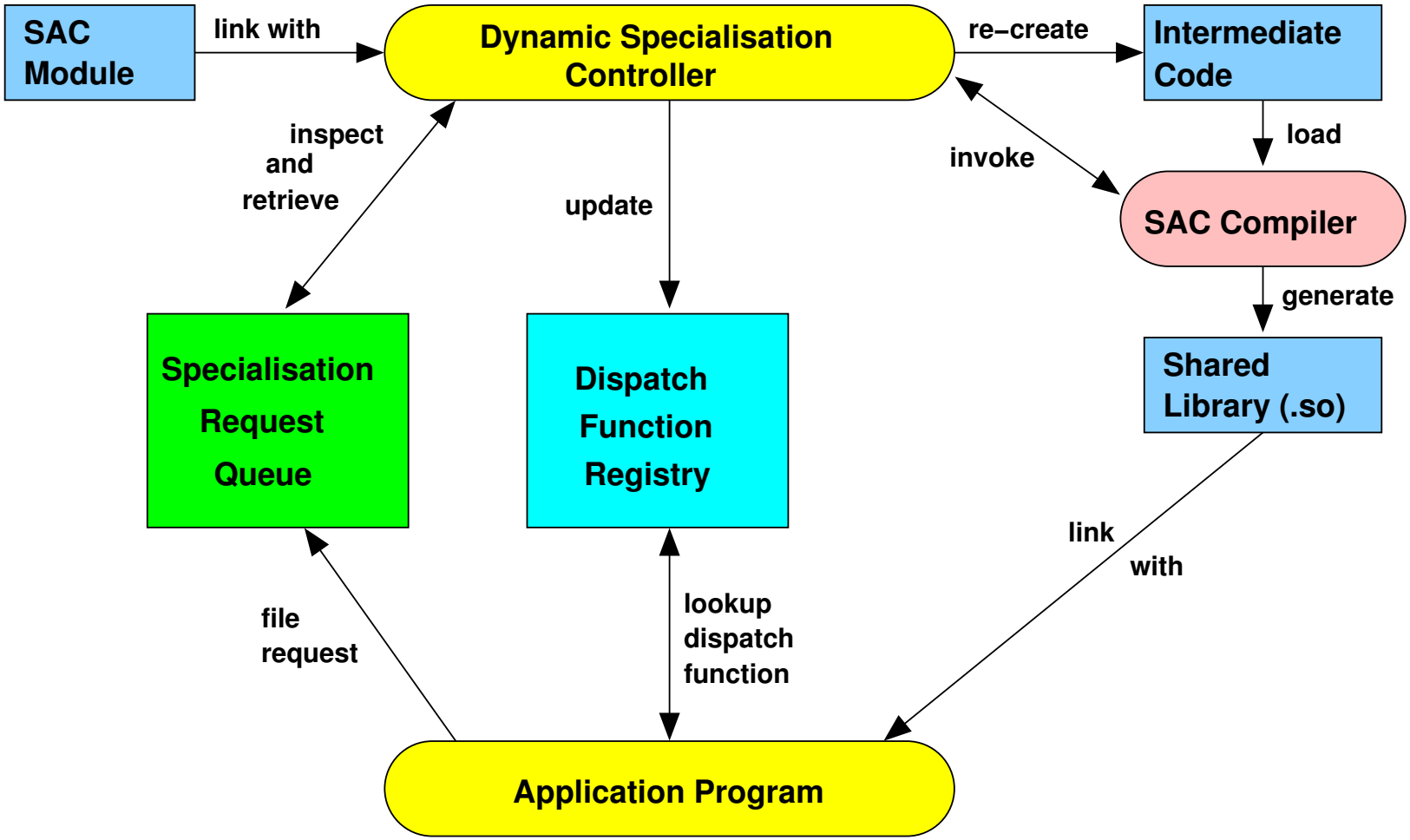
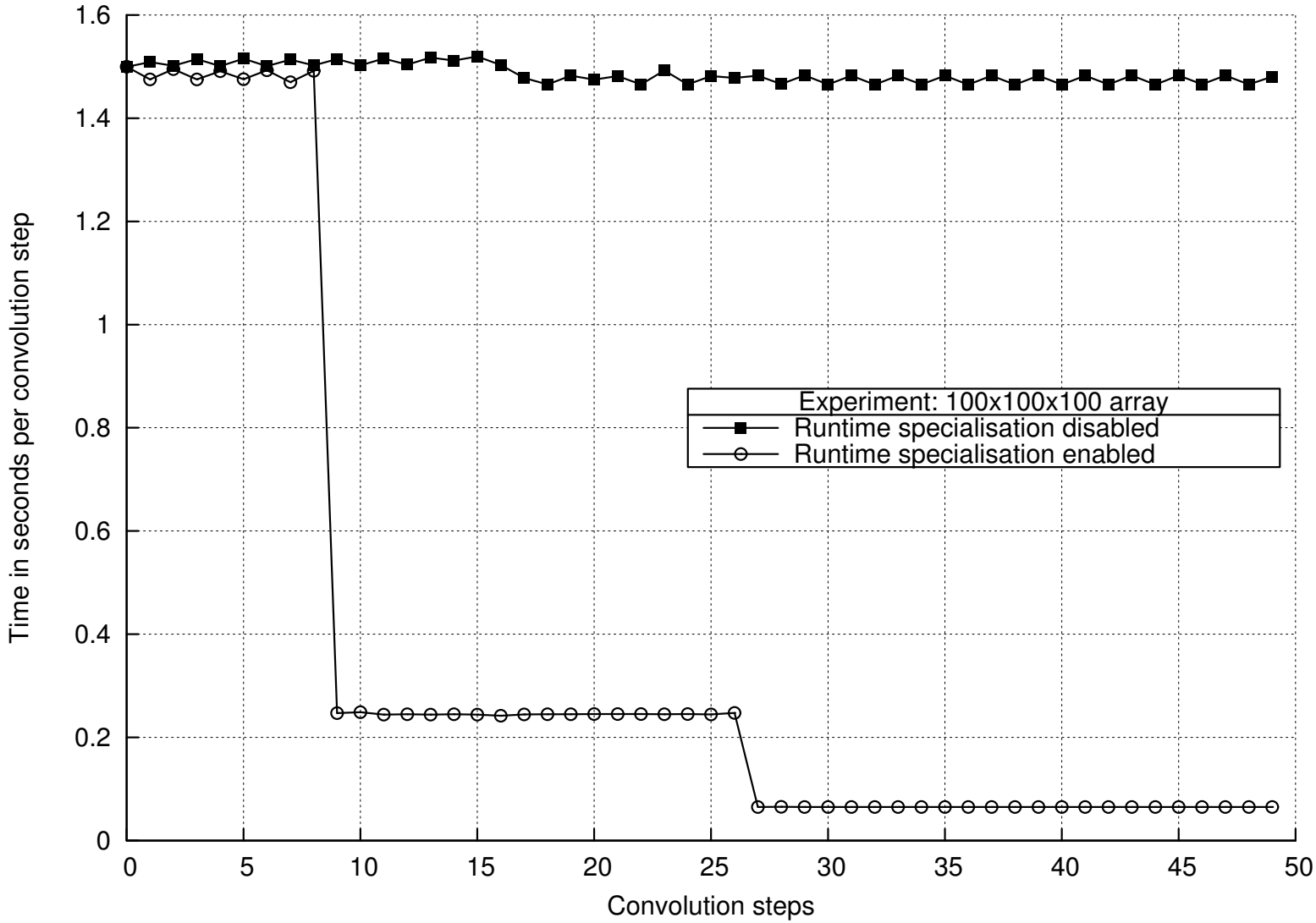
Idea:

- 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

Adaptive Dynamic Compilation Architecture



Evaluation Example: 3-d Convolution 100x100x100



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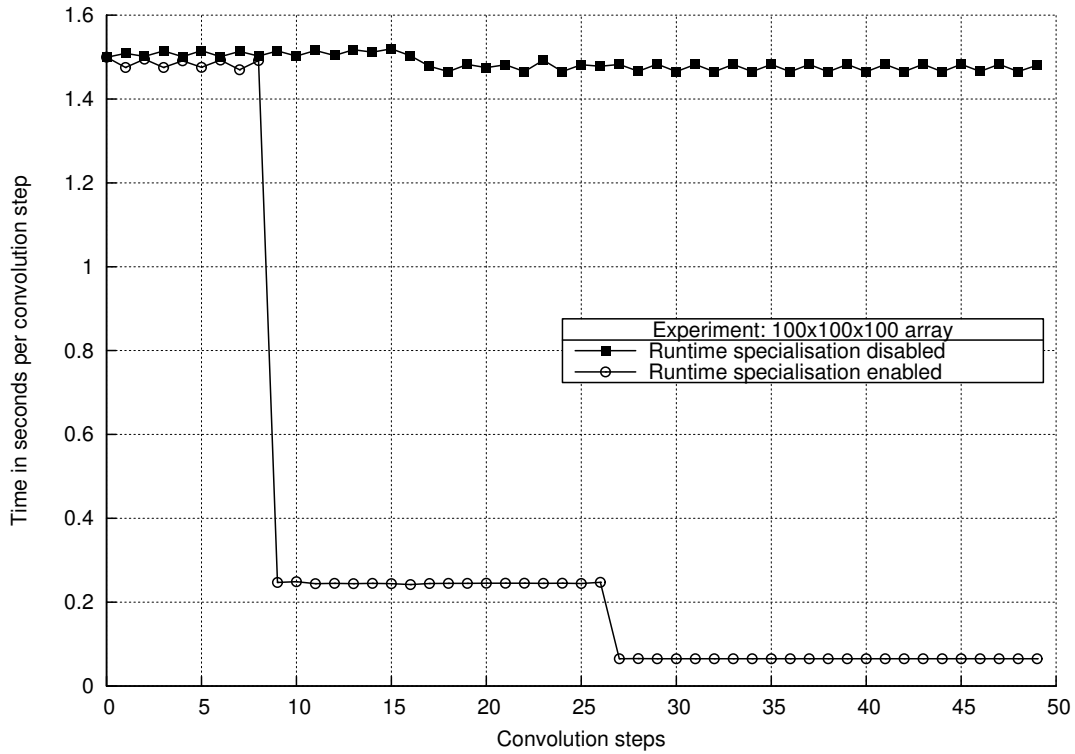

Key question:

How can we speed up the availability of adapted code ?

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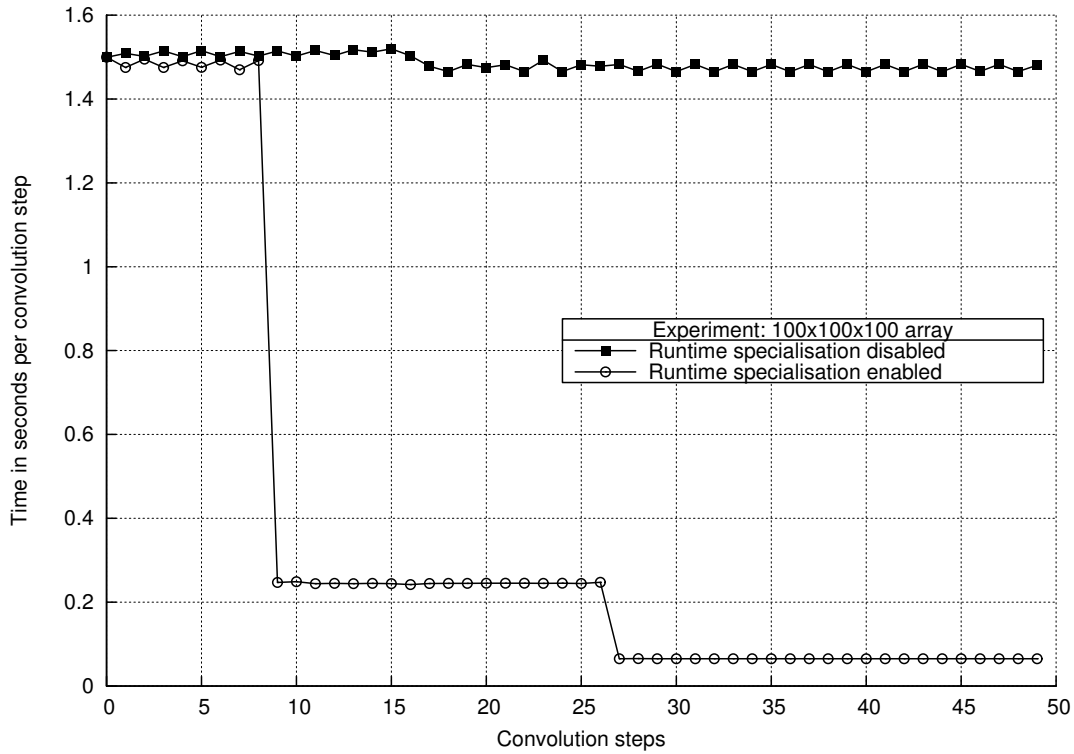

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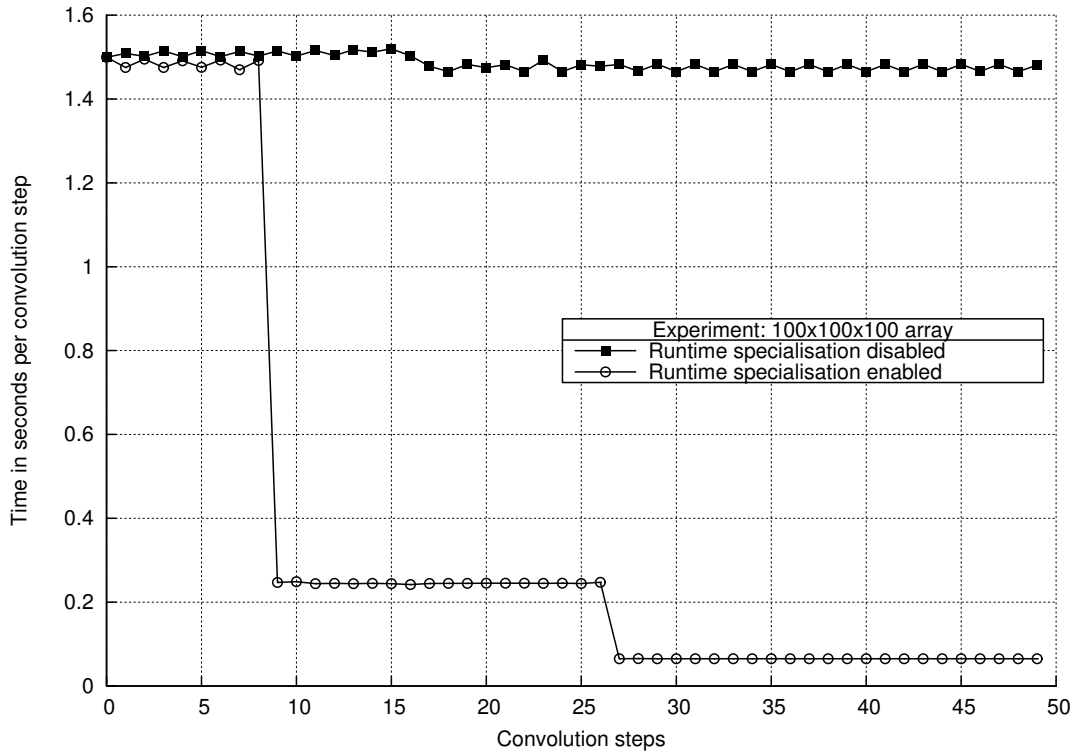

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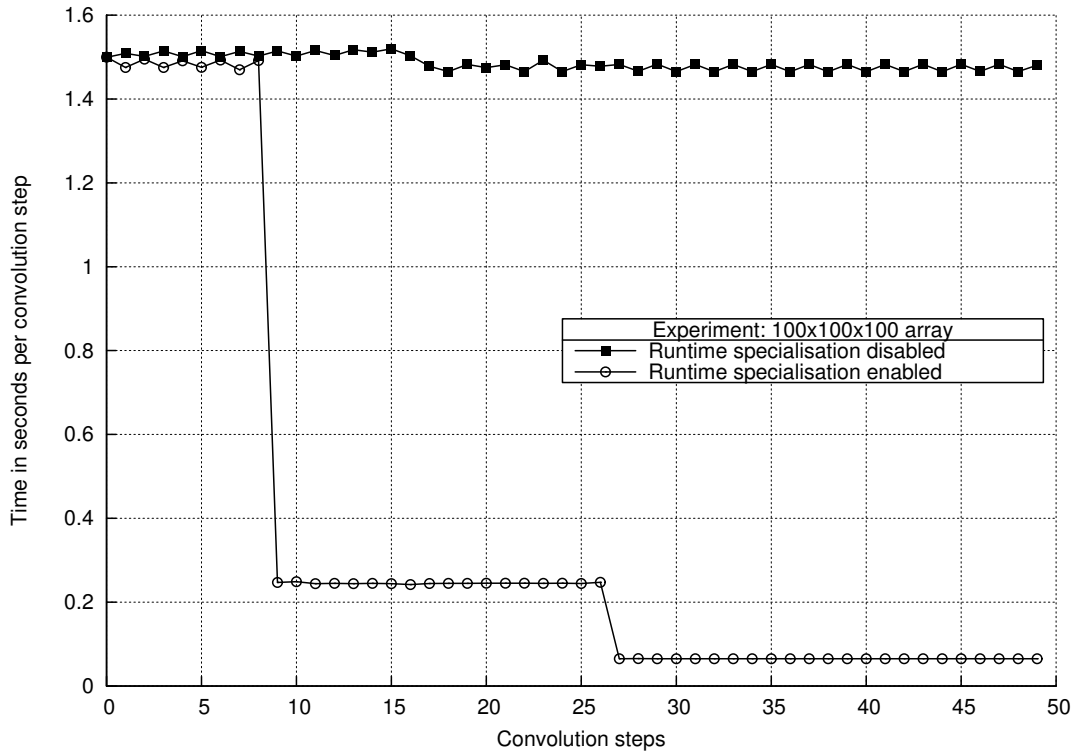

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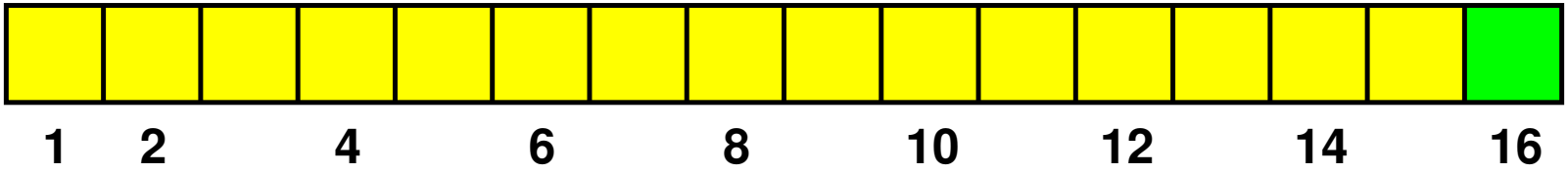
- Accelerate SAC compiler ?
- Parallelise code adaptation !
- Make adapted code persistent !

Parallel Asynchronous Adaptive Specialisation

First approach: dedicated specialisation core:



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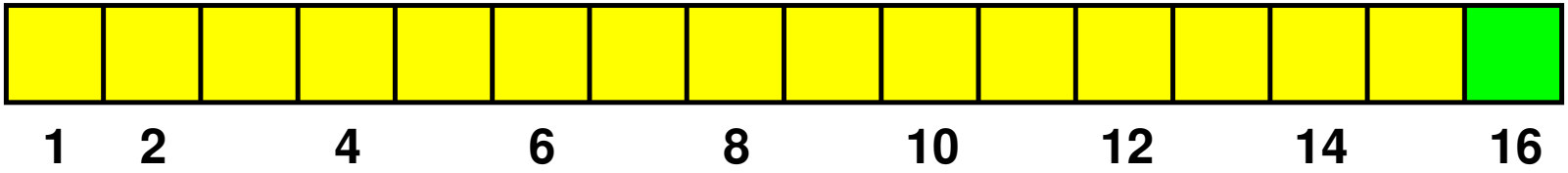

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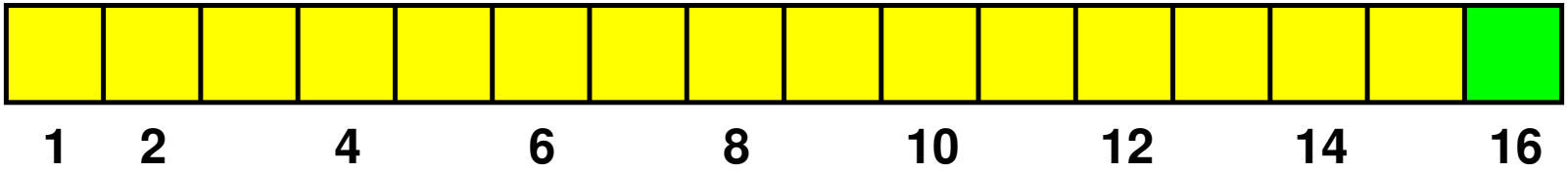

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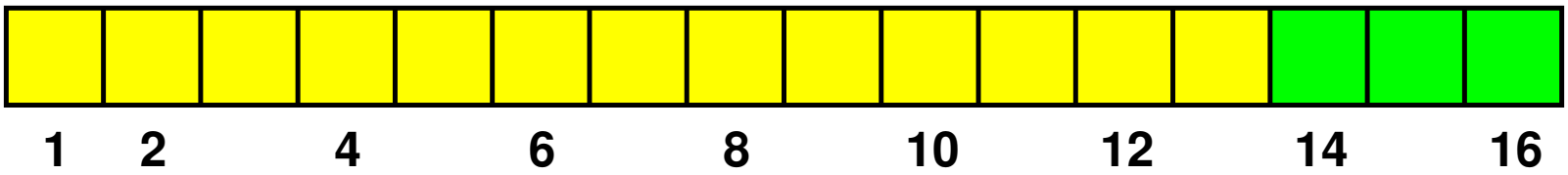
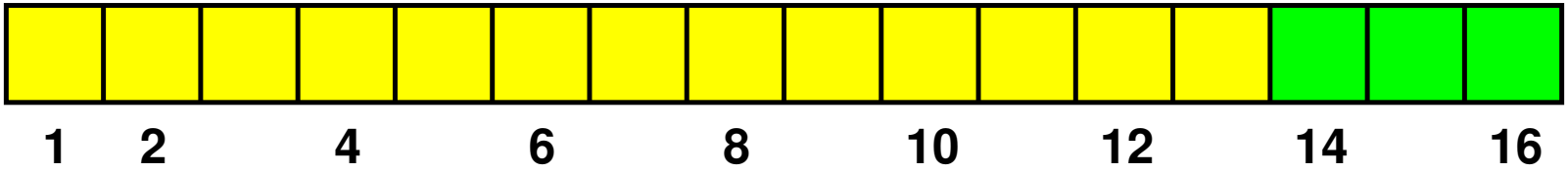
Solution:

- Use configurable division of cores:



Concurrent Dynamic Specialisation Reloaded

Second approach: configurable number of specialisation core



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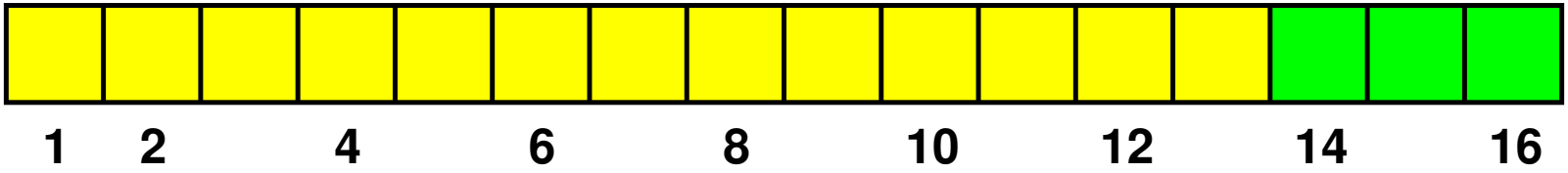

More observations:

- Dynamic specialisation often reaches fixed point
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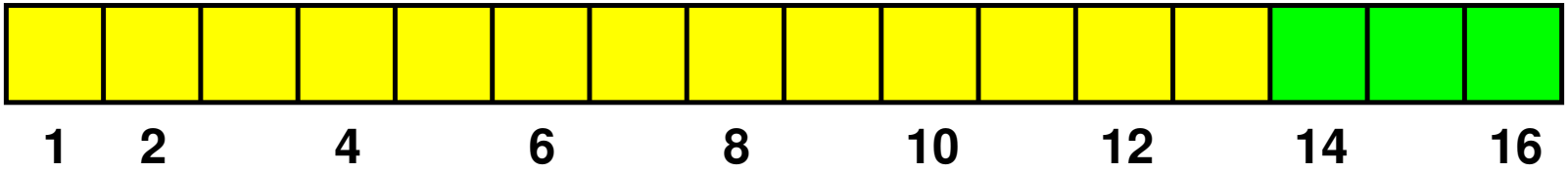

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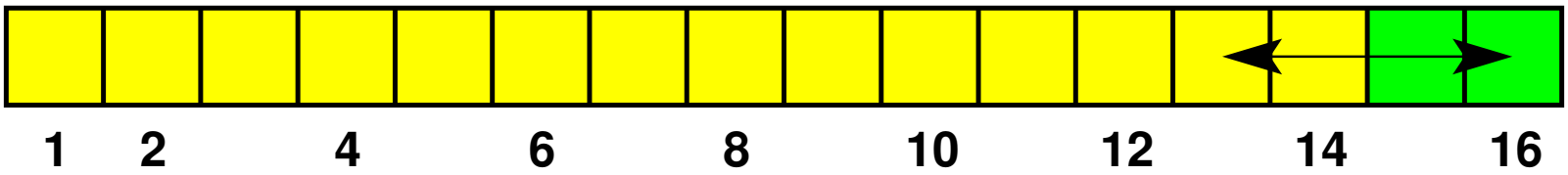
Solution:

- Dynamically adjust number of specialisation cores:



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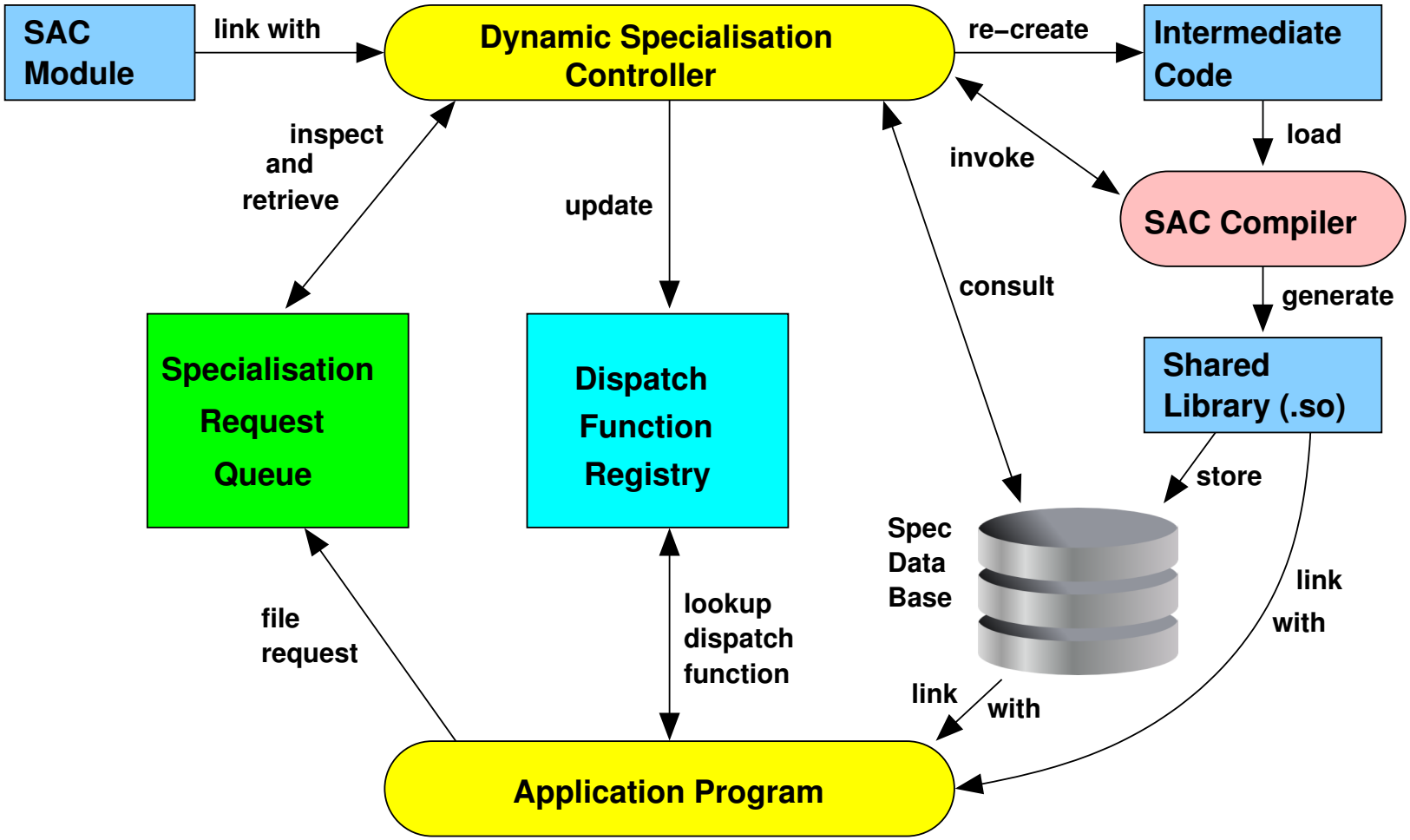
Solution:

- 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.

Adaptive Dynamic Compilation Architecture 2.0



Conclusion

Classical trade-off:

Software Engineering Principles

vs

Runtime Performance Requirements

Solution:

Large-scale Specialisation and Optimisation

plus

Dynamic Code Adaptation

Future work:

- Complete implementation
- More case studies
- Extensive evaluation