PetaBricks

A Language and Compiler for Algorithmic Choice

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MIT - CSAIL

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Outline

1. Introduction
   - Motivating Example
   - Language & Compiler Overview
   - Why choices
2. PetaBricks Language
   - Key Ideas
   - Compilation Example
   - Other Language Features
3. Results
   - Benchmarks
   - Scalability
   - Variable Accuracy
4. Conclusion
   - Final thoughts

Algorithmic choice

Mergesort
(N-way)

Algorithmic choice

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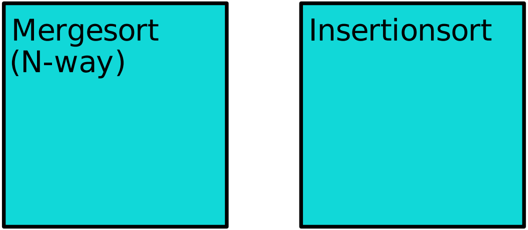
Algorithmic choice



Algorithmic choice

Mergesort (N-way)

Insertionsort

Radixsort

Algorithmic choice

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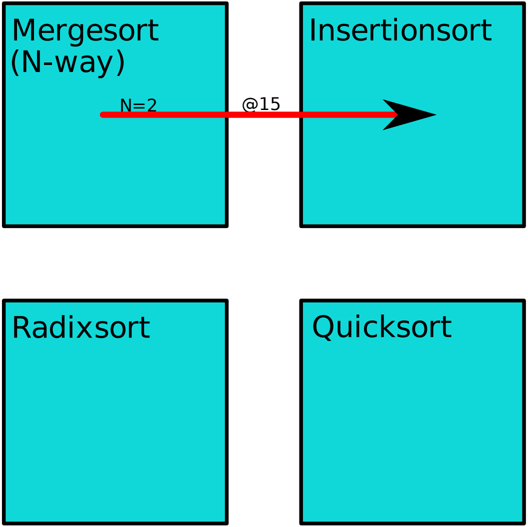
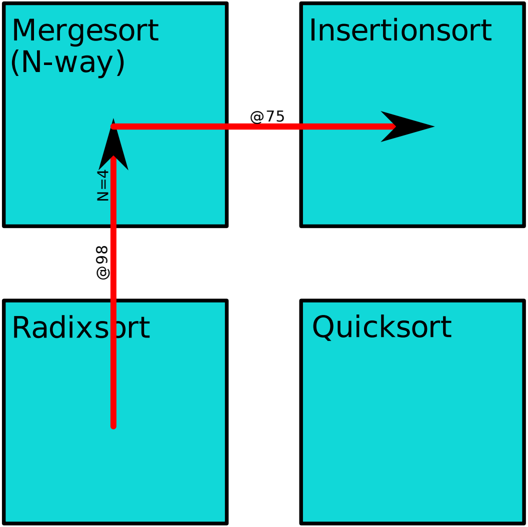
Quicksort

Algorithmic choice



STL Algorithm

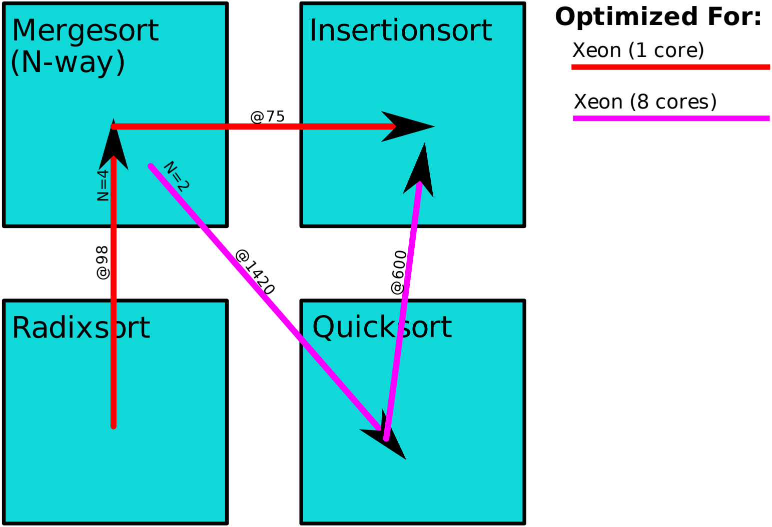
Algorithmic choice



Optimized For:

Xeon (1 core)

Algorithmic choice



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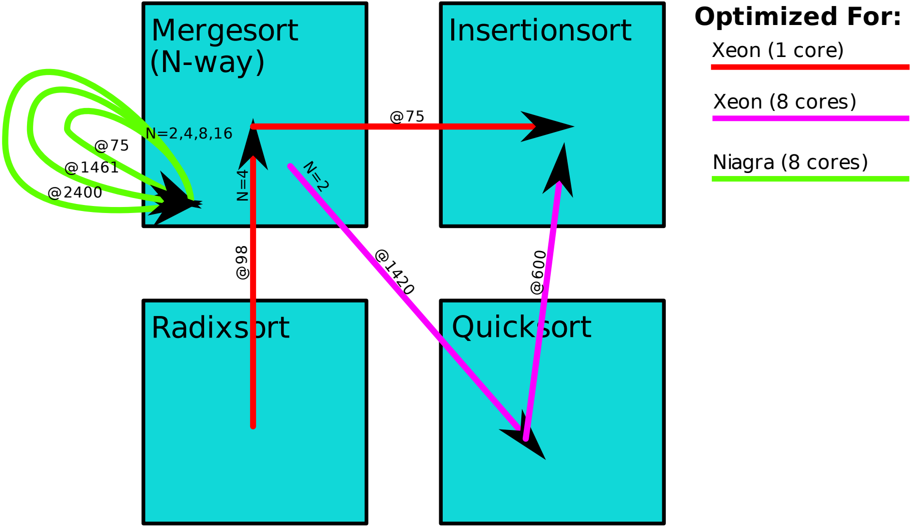

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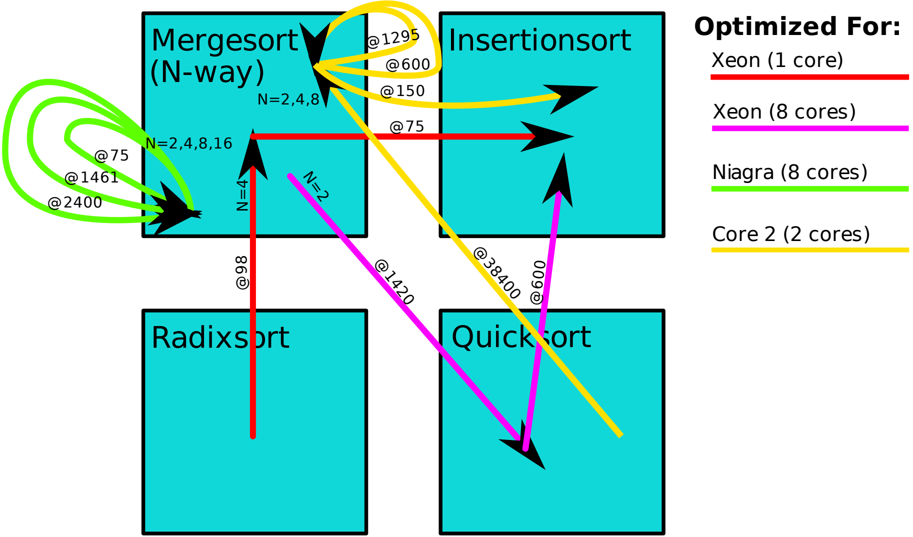

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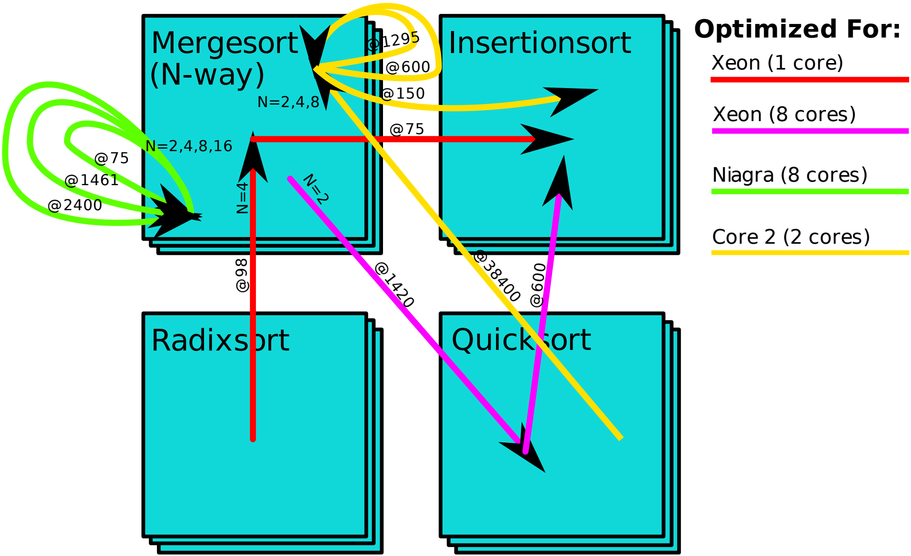

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    - Choice as a fundamental language construct
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    - Automatically parallelized

Sort in PetaBricks

```
transform Sort
from A[n]
to B[n]
{
  from(A a) to(B b) {
    tunable WAYS;
    /* Mergesort */
  } or {
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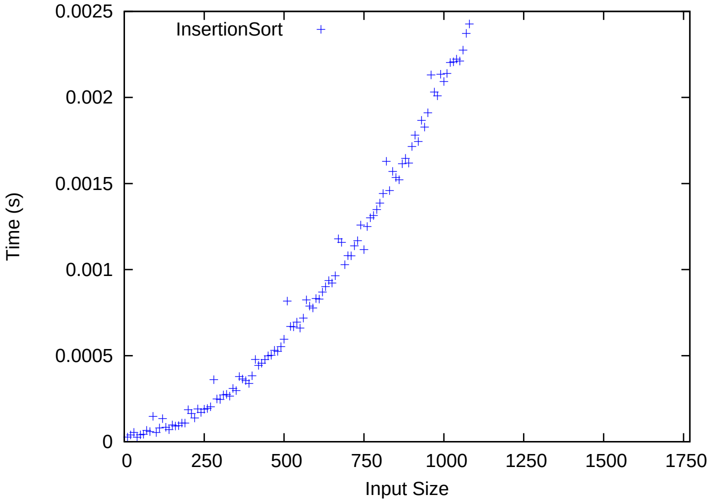
    - Trained with full number of threads
    - Under 1 minute for Sort
- Results fed back into the compiler
- Final binary created

Sort algorithm timings[1]



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[1] On an 8-way Xeon E7340 system

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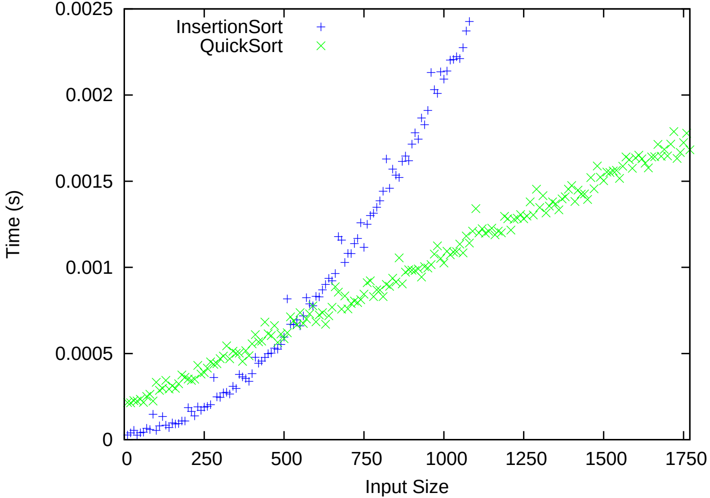

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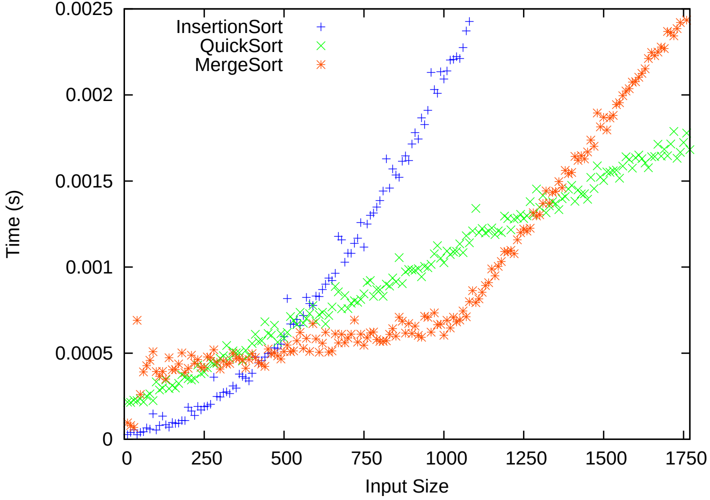

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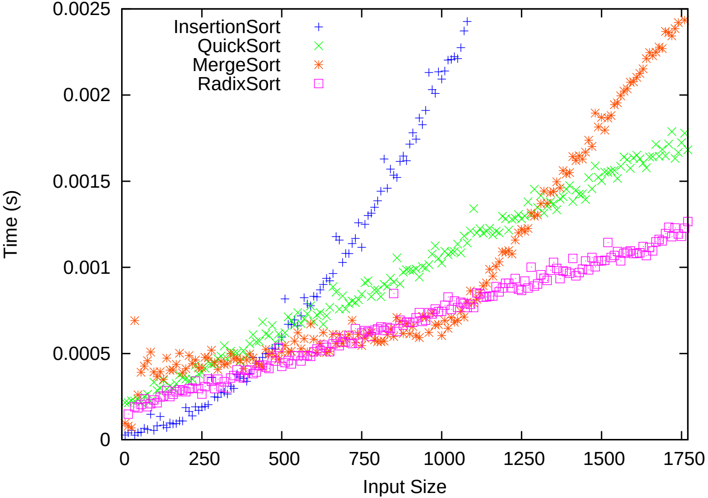

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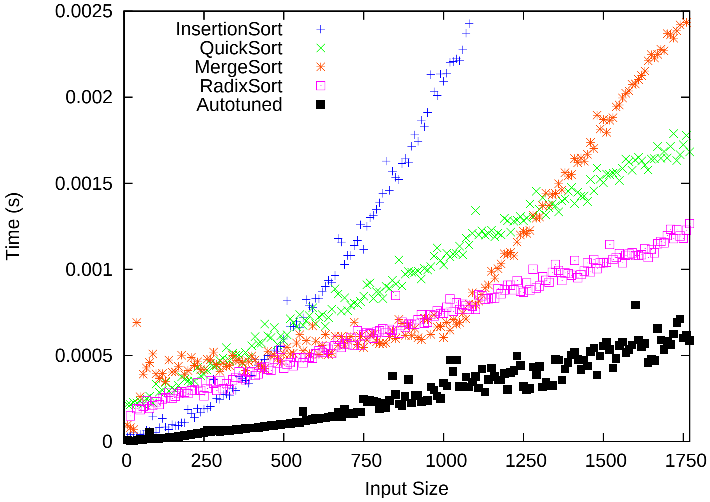

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Timings on different architectures

		Trained on			
		Mobile	Xeon 1-way	Xeon 8-way	Niagara
Run on	Mobile	-	1.09x	1.67x	1.47x
	Xeon 1-way	1.61x	-	2.08x	2.50x
	Xeon 8-way	1.59x	2.14x	-	2.35x
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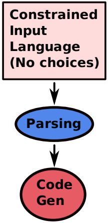
Early compilers



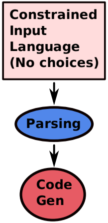
Constrained Input Language (No choices)

Parsing

Code Gen

- Early computers (and compilers) were weak

Early compilers



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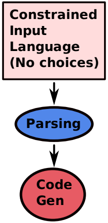

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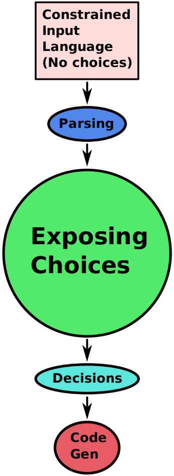
- Parsing and code generation dominated compilation
- Needed a constrained input language to simplify compilation

Current compilers



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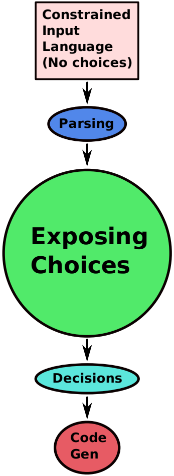

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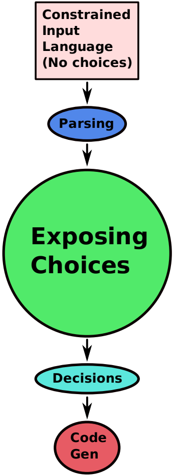

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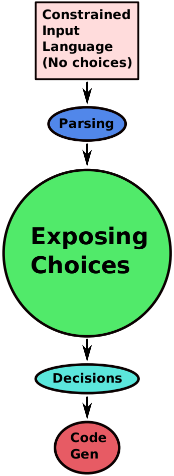

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  - Iteration order choice
  - Parallelism strategy choice
  - Data layout choice

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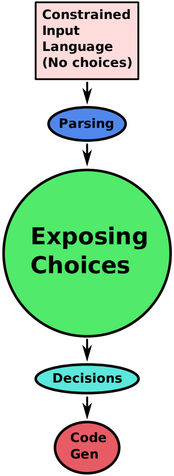

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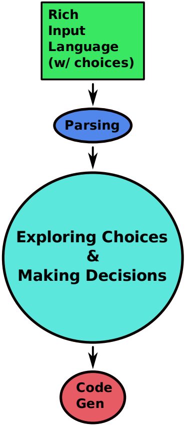
- Compiler must perform heroic analysis to reconstruct other choices

PetaBricks compiler



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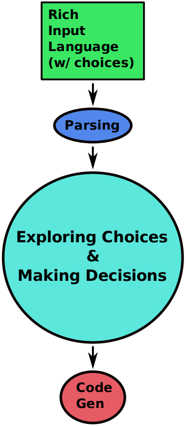

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- The programmer defines the space of legal
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  - Iteration orders (include parallel)
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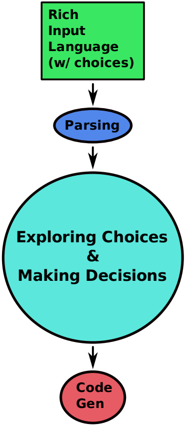

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- Allow compilers to focus on exploring choices
- Compiler no longer needs to reconstruct choices

Future-proof programs

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- Programs change with architecture, available cores, inputs, etc

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Algorithmic choice in the language

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Algorithmic choice in the language

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- Programmer can define multiple rules to compute the same data
- Compiler re-use rules to create hybrid algorithms
- Can express choices at many different granularities

Synthesized outer control flow

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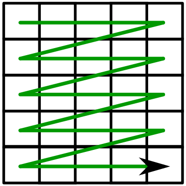
- Another choice that the programmer should not make

Synthesized outer control flow



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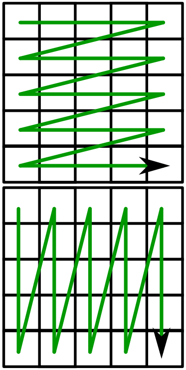

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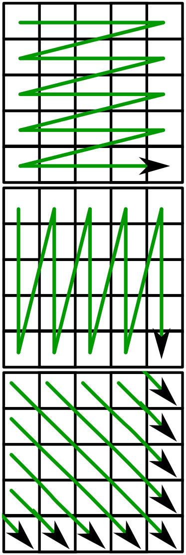

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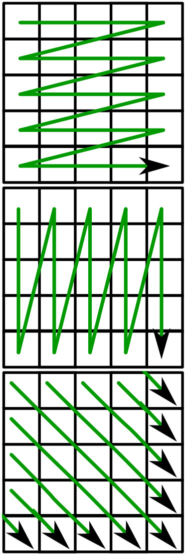

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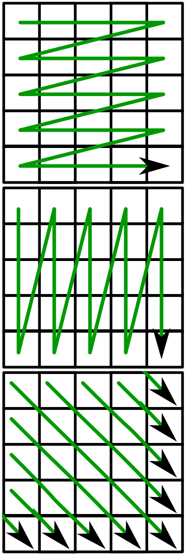

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- Allows compiler to explore choice space

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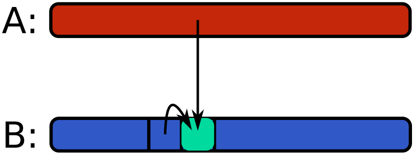

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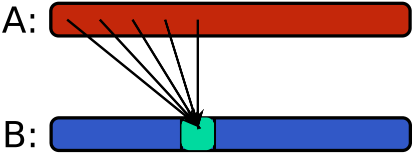

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Applicable regions	Choice grids	Choice dependency graph

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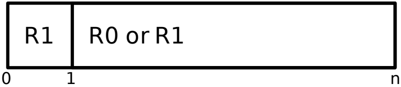

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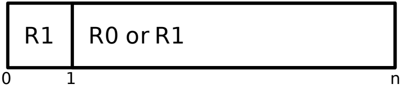

- Applicable regions map rules → symbolic data
- Choice grids map symbolic data → rules

Choice dependency graph

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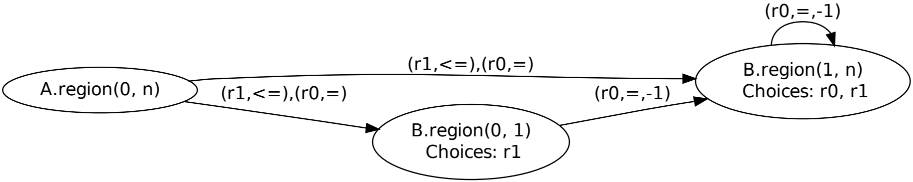

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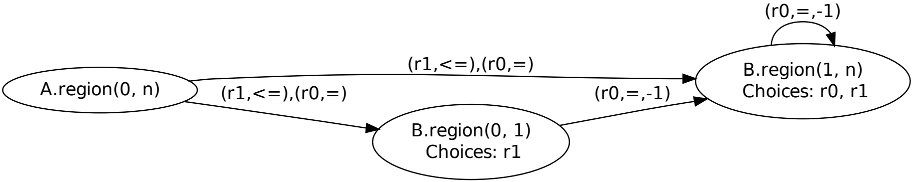

- Adds dependency edges between symbolic regions

Choice dependency graph

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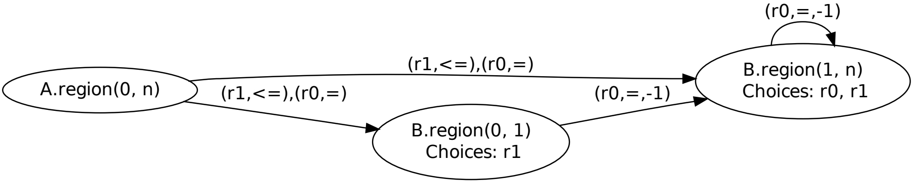

- Adds dependency edges between symbolic regions
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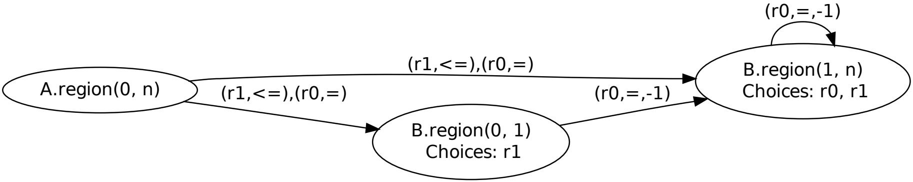

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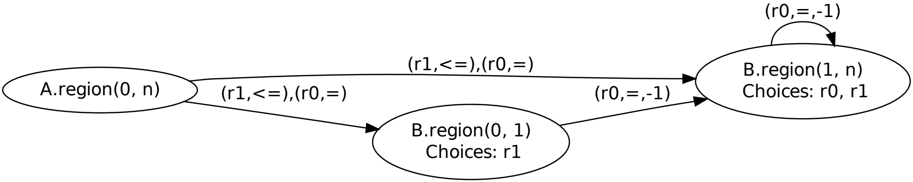

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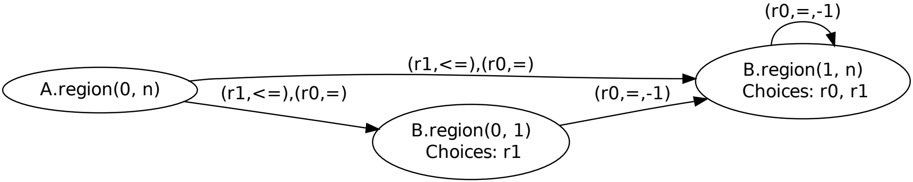

- Adds dependency edges between symbolic regions
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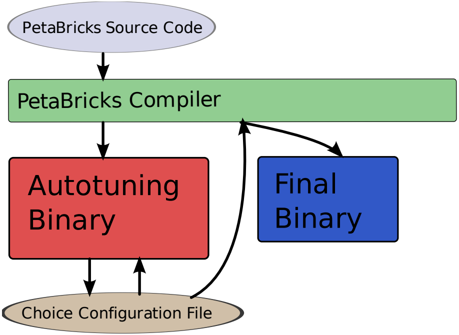
- Many compiler passes on this IR to:
    - Simplify complex dependency patterns
    - Add choices

Code generation



1. PetaBricks source code is compiled

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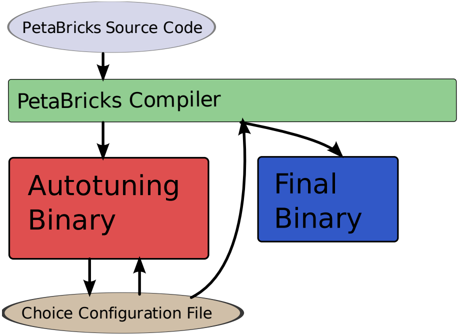

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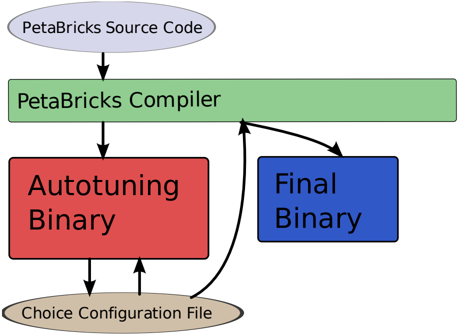

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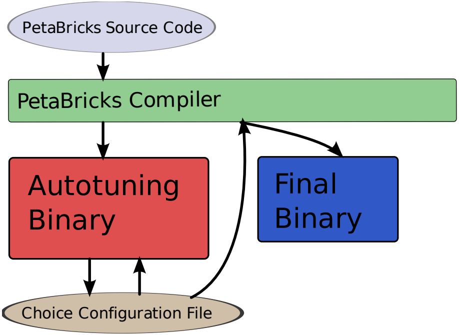

1. PetaBricks source code is compiled
2. An autotuning binary is created
3. Autotuning occurs creating a choice configuration file
4. Choices are fed back into the compiler to create a final binary

Autotuning

- Based on two building blocks:
    - A genetic tuner
    - An *n*-ary search algorithm

Autotuning

- Based on two building blocks:
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Autotuning

- Based on two building blocks:
  - A genetic tuner
  - An *n*-ary search algorithm
- Flat parameter space
- Compiler generates a dependency graph describing this parameter space
- Entire program tuned from bottom up

Parallel Runtime Library

- Task-based parallel runtime
- Thread-local decks of runnable tasks

Parallel Runtime Library

- Task-based parallel runtime
- Thread-local decks of runnable tasks
- Use a work-stealing algorithm similar to that of Cilk

Outline

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More PetaBricks features

- Automatic consistency checking
- The *tunable* keyword
- Call external code
- Custom training data generators
- Matrix *versions* for iterative algorithms
- Rule priorities
- `where` (clause for limiting applicable regions)
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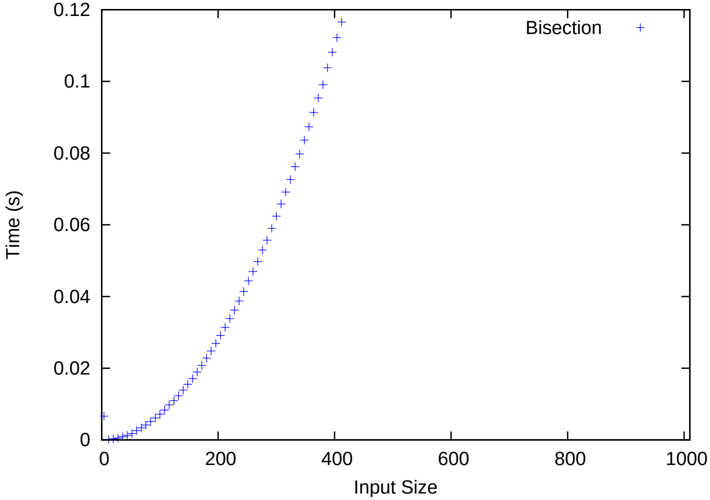
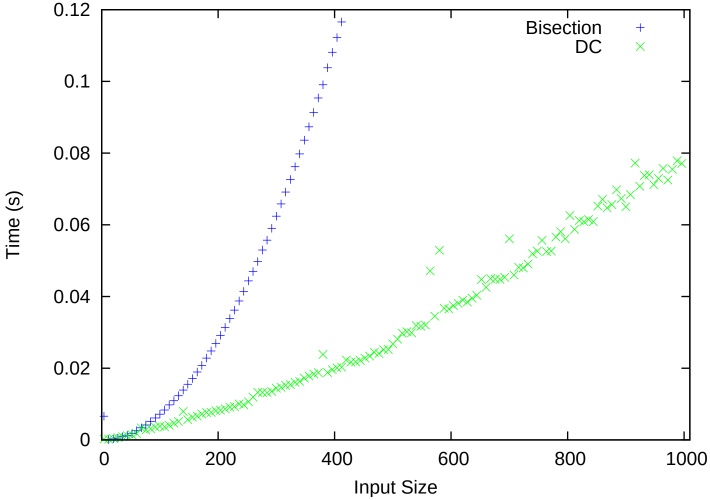
Eigenvector Solve

- Bisection
- QR decomposition
- Divide and conquer

Eigenvector Solve



Eigenvector Solve



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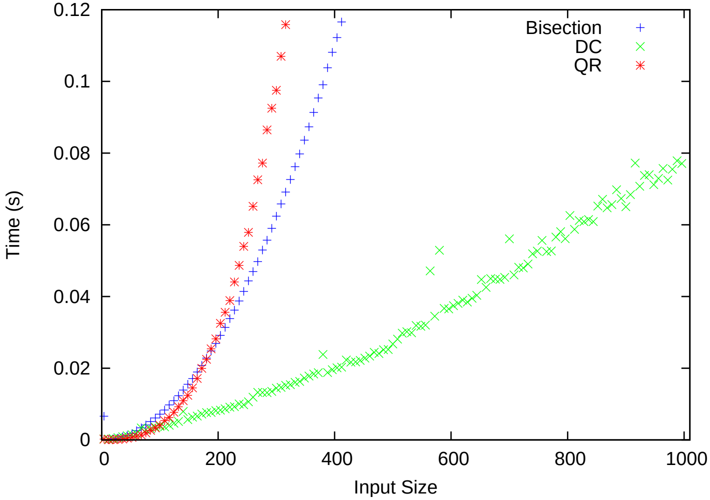

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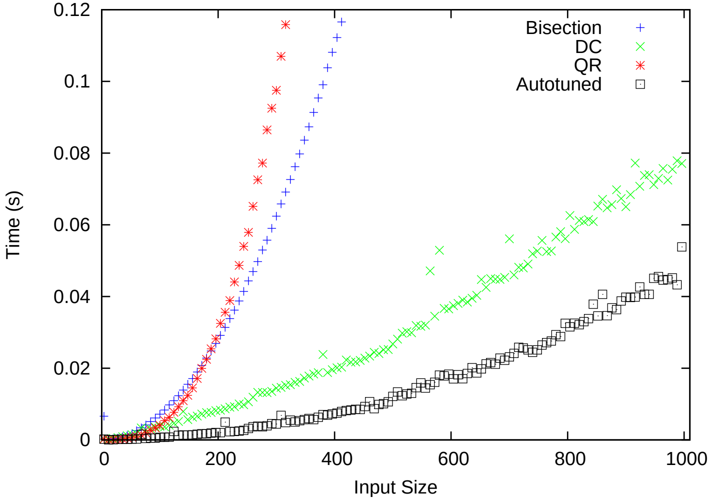

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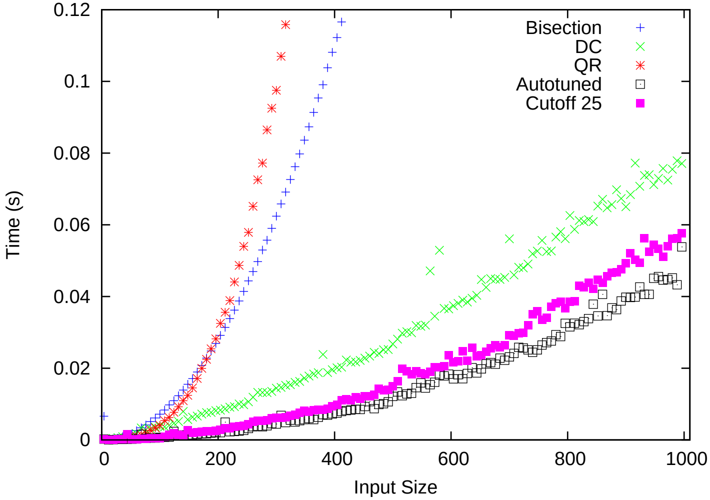
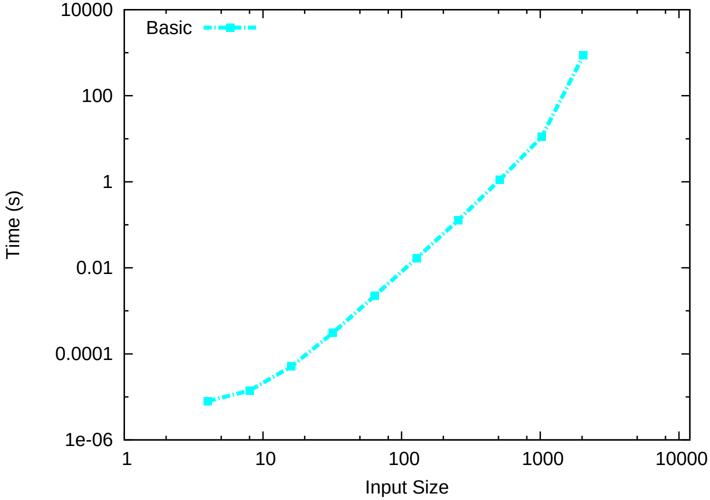


Matrix Multiply

- Basic
- Recursive decompositions
- Strassen's algorithm
- Iteration order (blocking)
- Transpose

Matrix Multiply



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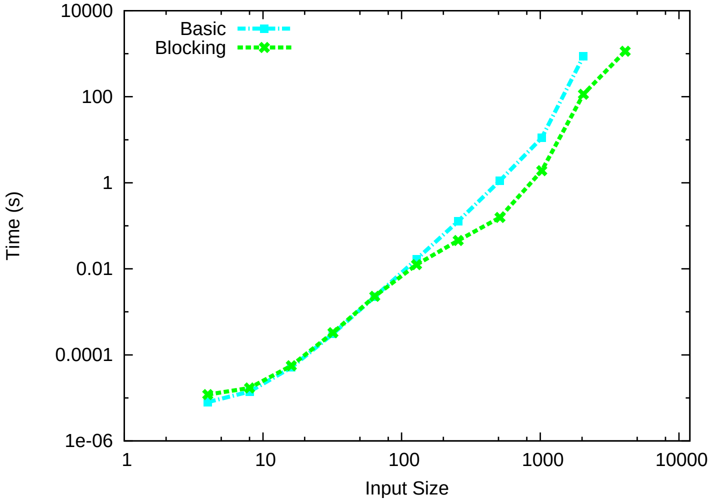

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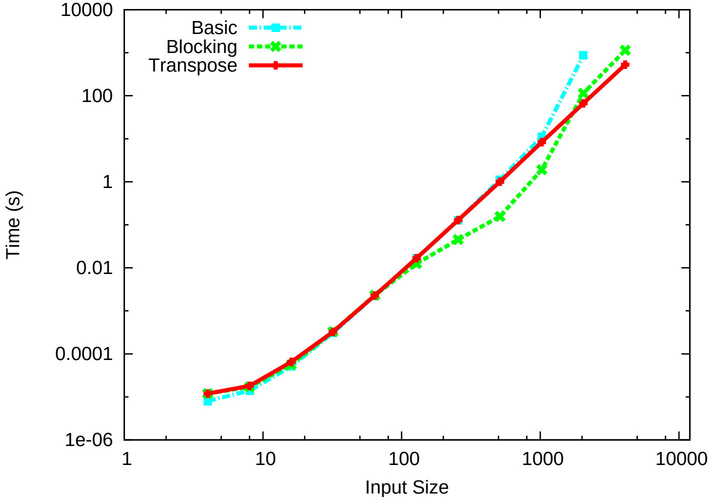

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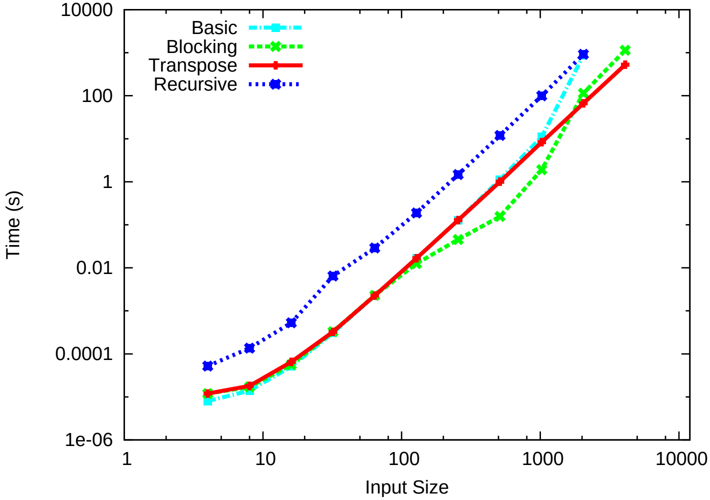

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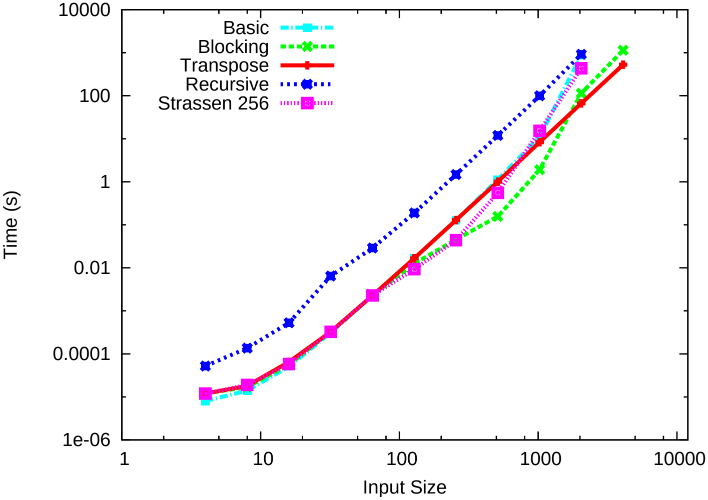

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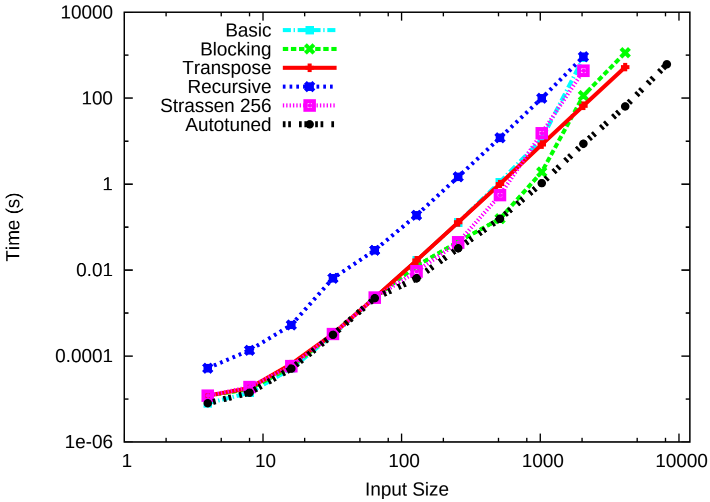

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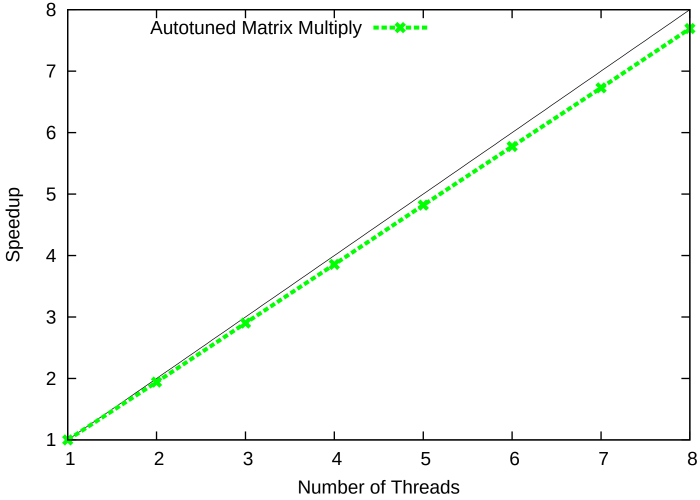
Scalability



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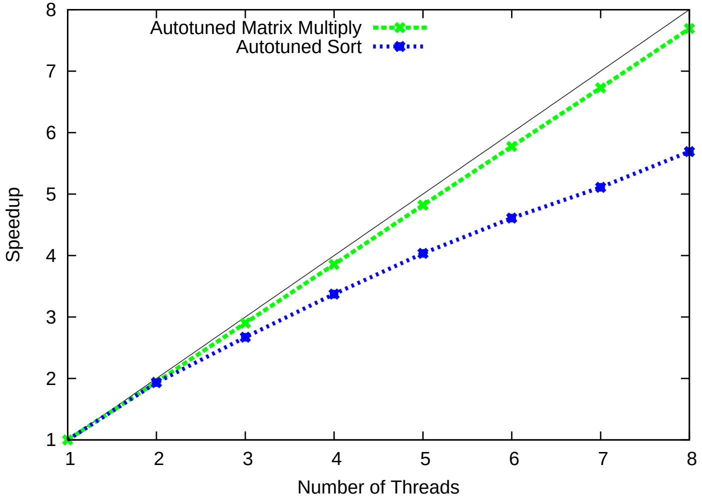

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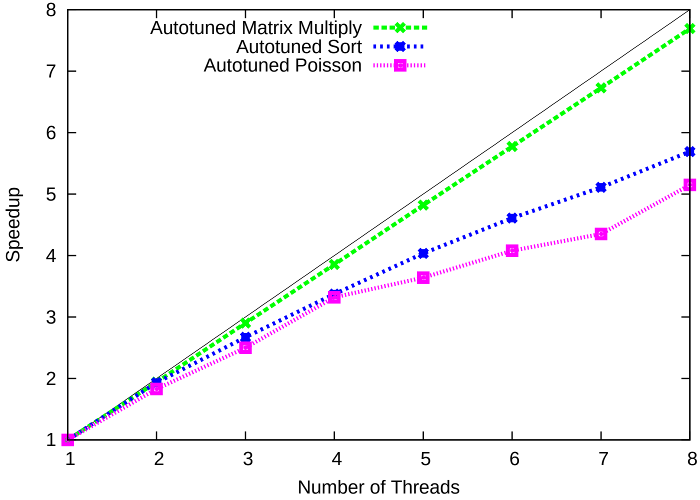

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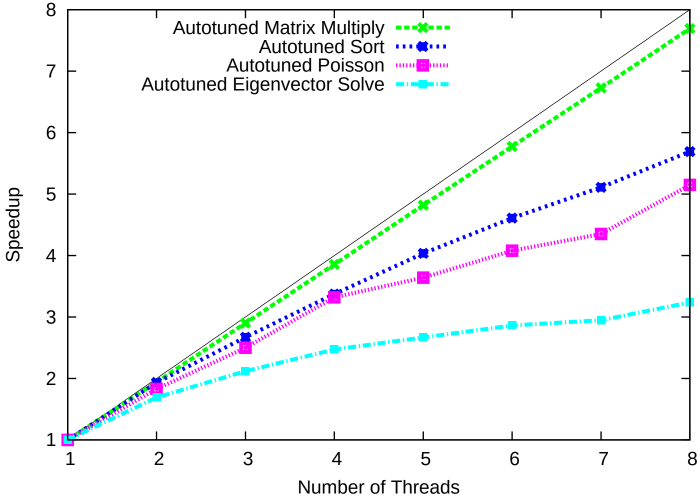

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Variable accuracy

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    - Iterative convergence
    - Grid coarsening
    - Others

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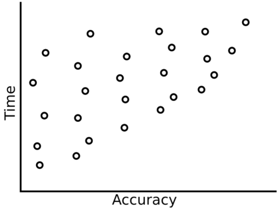

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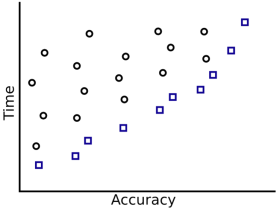

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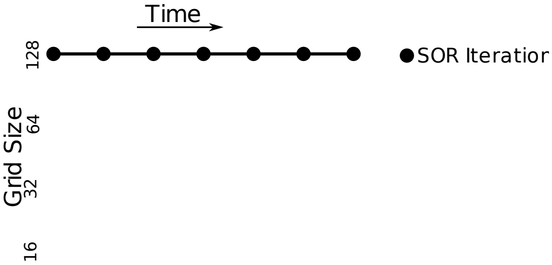
  - Others
- Compiler/autotuner should be aware of variable accuracy
- Compiler can examine optimal frontier of algorithms

Poisson's equation

- A variable accuracy benchmark
- Accuracy level expressed as a template parameter
- Autotuner exploits variable accuracy in a general way
- Choices:
    - Direct solve
    - Jacobi iteration
    - Successive over relaxation
    - Multigrid

Choices in Multigrid



- SOR is an iterative algorithm

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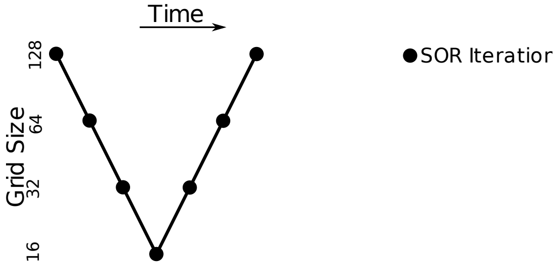

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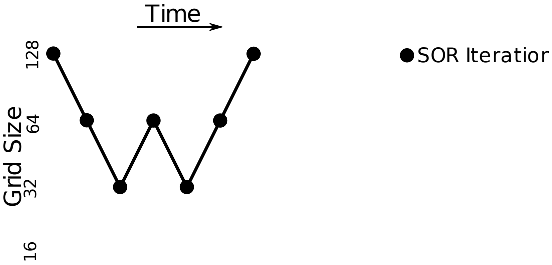

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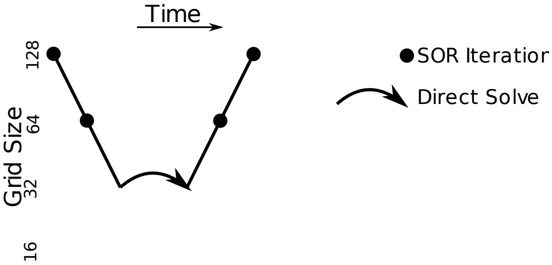

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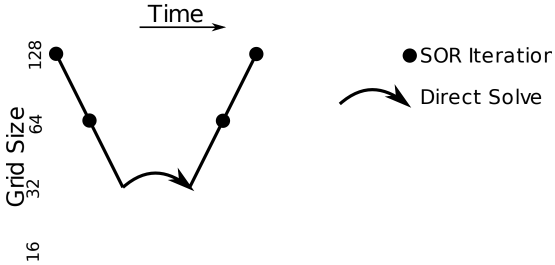

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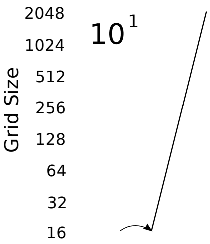
- Many standard shapes: V-Cycle, W-Cycle, etc
- Direct solver
- Different shapes = different algorithms

Autotuned V-cycle shapes for different accuracy requirements



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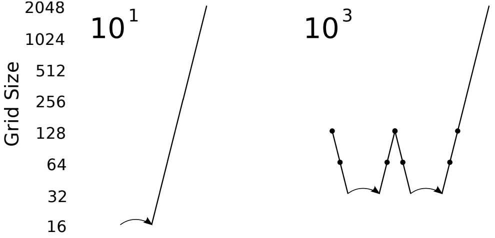

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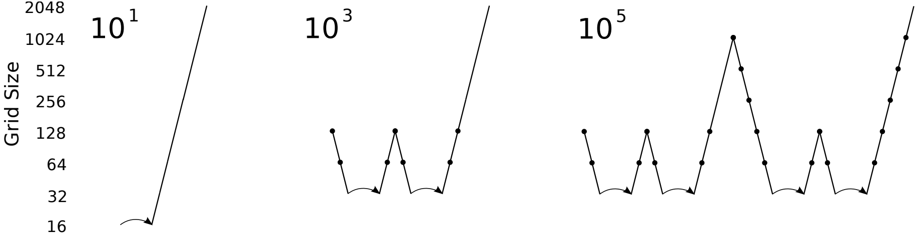

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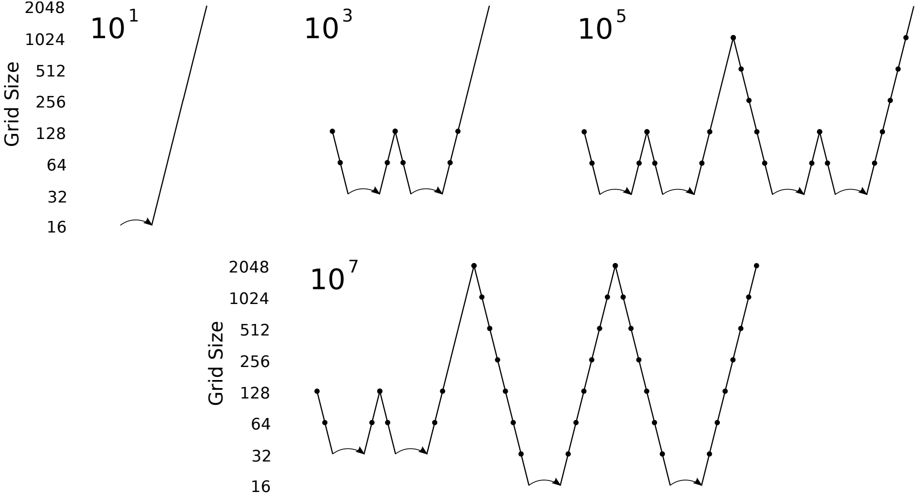
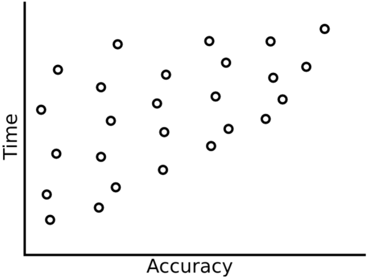


Dynamic programming technique for autotuning Multigrid



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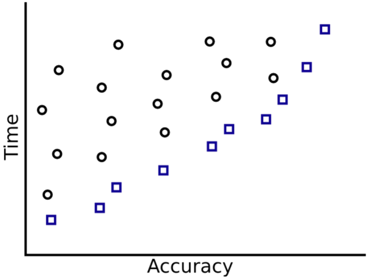

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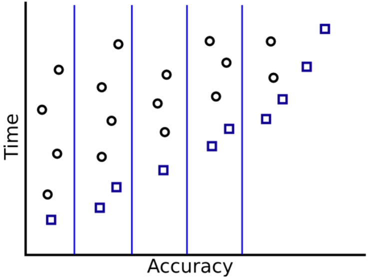

- Partition accuracy space into discrete levels

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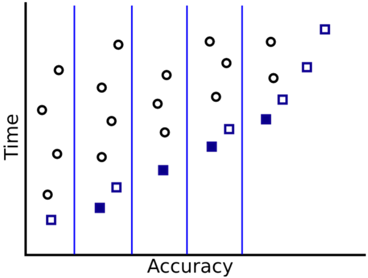

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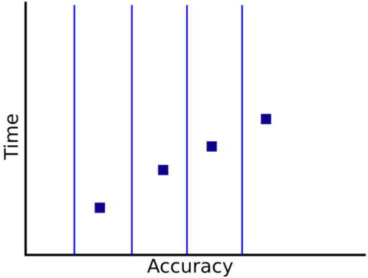

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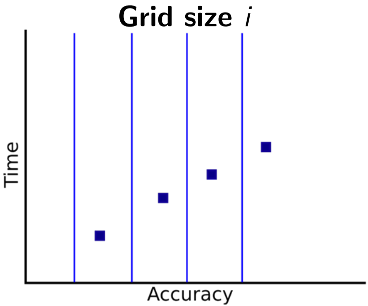

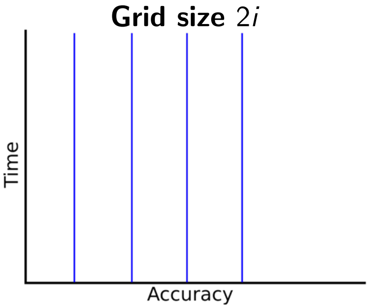

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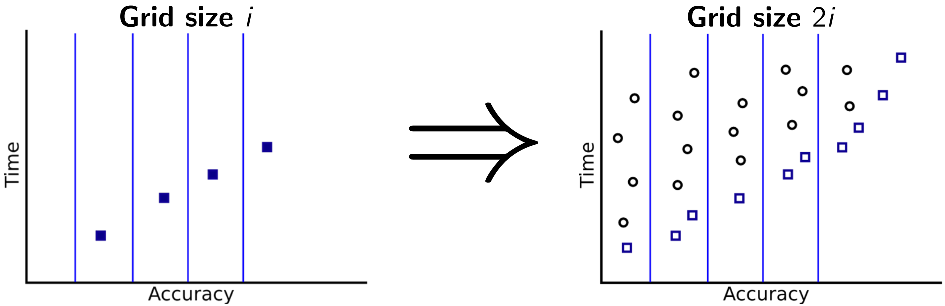

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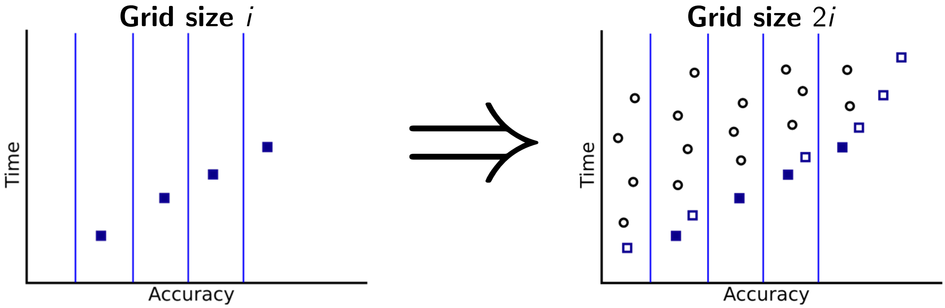

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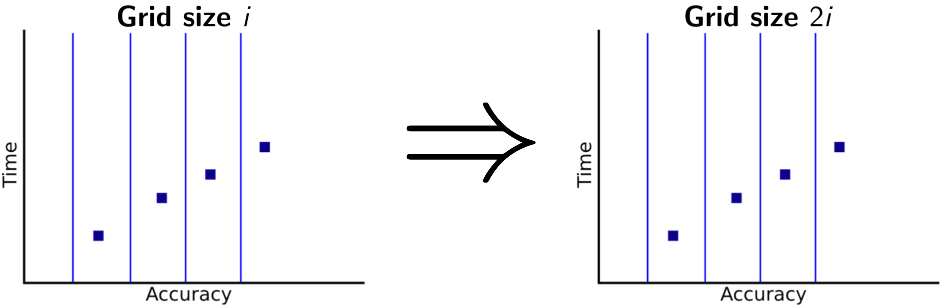

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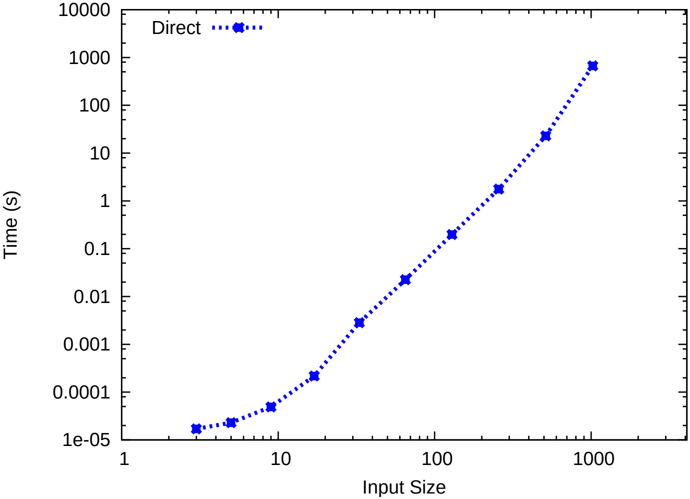
Poisson's Equation



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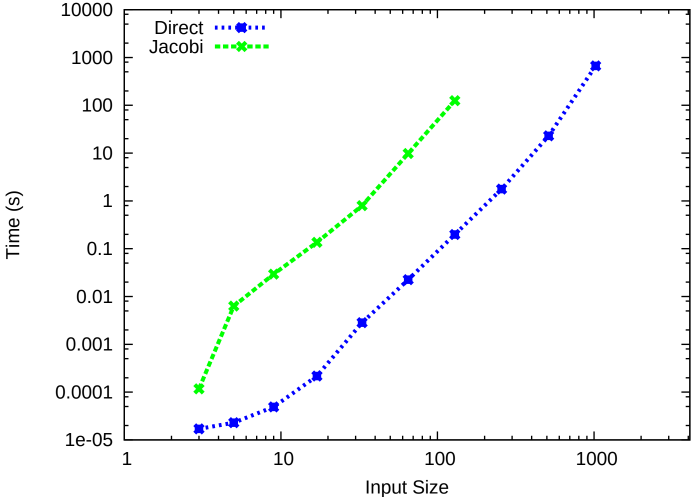

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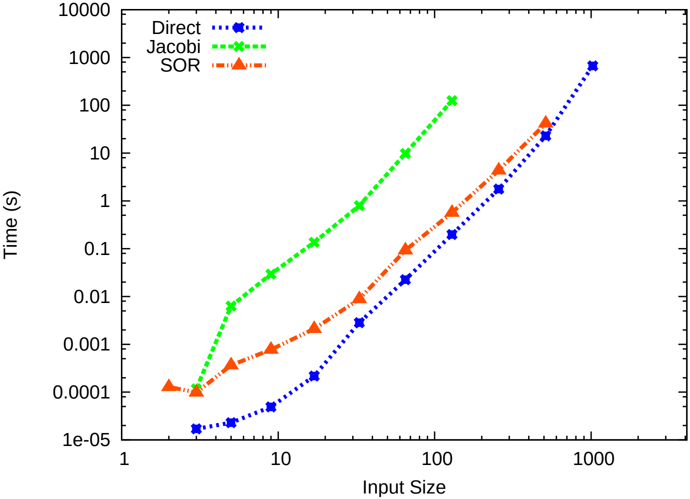

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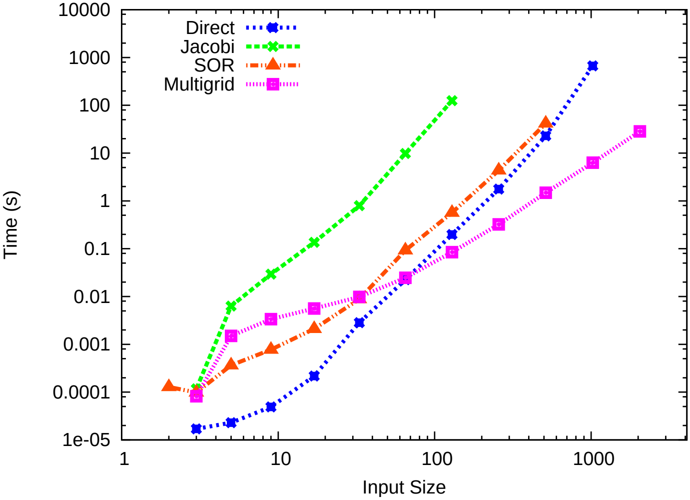

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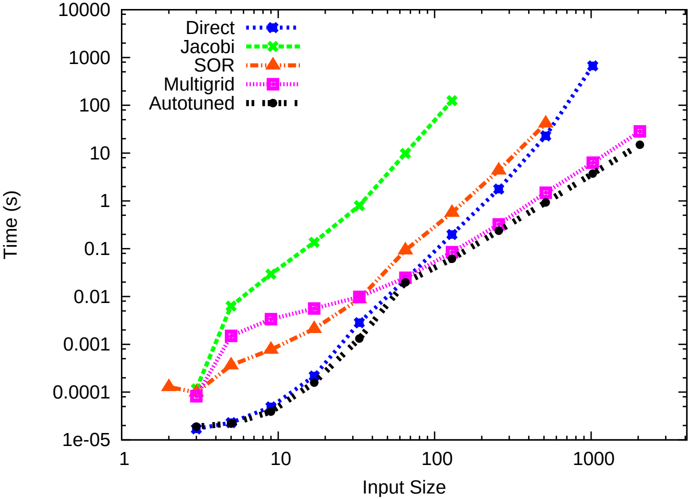

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Related work

- Languages
    - Sequoia
- Libraries & domain specific tuners
    - STAPL
    - ATLAS
    - FFTW
    - SPARSITY
    - SPIRAL
    - ...

For more information

- PetaBricks makes programs **future-proof**, by allowing them to adapt to new architectures

- We plan to released PetaBricks at the end of summer
- Sign up for our mailing list to be notified
- For more information see: `http://projects.csail.mit.edu/petabricks/`

- Questions?

Thank you!