PQL: A Purely-Declarative Java Extension for Parallel Programming

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WRITING PARALLEL PROGRAMS IS HARD

- locking
- races
- side effect order
- consistency models
- distributing computations

...

EASIER PARALLELISM

Approach	Problems	User actions
map-reduce	emb. parallel + aggregation	split computation
fork-join	divide-and-conquer	(recursively) divide up problem
PLINQ	SQL-like, over containers	tag parallel steps
Pregel	graph algorithms	split into graph computations, -mutations

Frameworks for *manual* parallelisation

Casual parallelism: *fully automatic*

CASUAL PARALLELISM

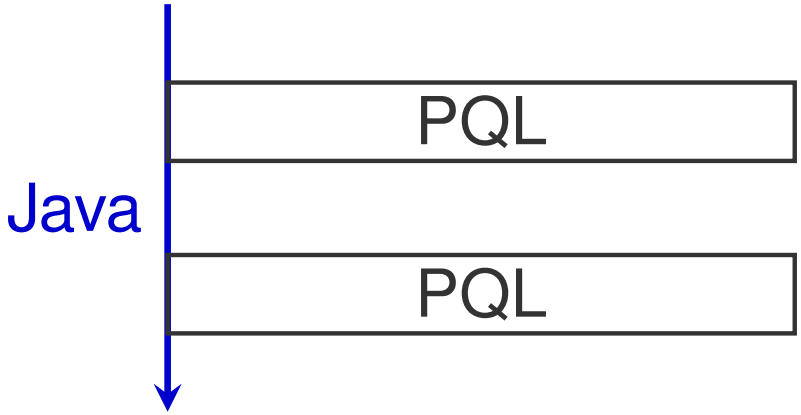
- Pitfalls:
  - Side effects
  - Order dependency

Declarative language

Specify the '*what*', not the 'how'

PQL/JAVA

- Declarative extension to Java:
  Parallel **Q**uery **L**anguage
- Fully automatic parallelisation
- Processes and builds Java containers



PQL/JAVA

- Declarative extension to Java:
  Parallel **Q**uery **L**anguage
- Fully automatic parallelisation
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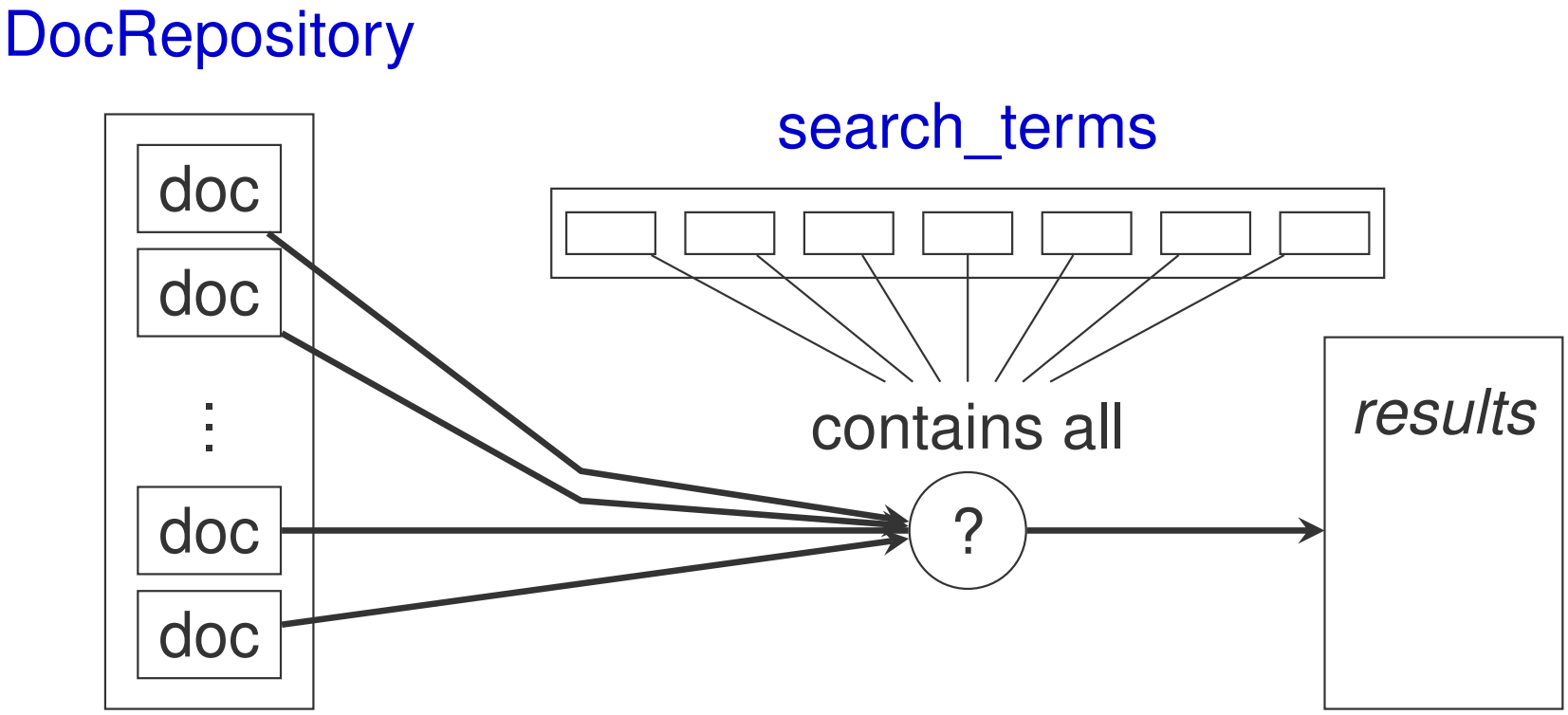
Java for sequential code, PQL for parallel code

PQL EXAMPLE




```
query (Set.contains(doc)):
        DocRepository.getAll().contains(doc)
        && forall x: doc.contains(search_terms[x]);
```

WHAT RICH LANGUAGE GIVES US CASUAL PARALLELISM?

- Embarrassingly parallel:
  Executable in $O(1)$ with enough CPUs
- Result from *Descriptive Complexity*:
  This language is precisely First-Order Logic[a]

Using $O(n^3)$ cores may be a bit much...

[a] if we assume a polynomial number of CPUs

MAKING FIRST-ORDER LOGIC MORE USEFUL

- Assert *or compute* results:
  - Finite set comprehension
  - SQL-style queries (minus aggregation, ordering)

x	$\exists y.$a$[x]$ = b$[y]$
0	true
1	false
2	false
3	true
⋮	⋮

representation:

$\Rightarrow \{0, 3, \ldots\}$

ADDING REDUCTION

reduce(add) x **over** i: x == a[i]

- log-parallel performance
- user-supplied reductors

PQL OVERVIEW

- +, −, . . . , ?:, ==, **instanceof**, &&, ||, −>
- **forall** , **exists**
- Java expressions as constants
- m[k], m.get(k), c.length, c.size(), s.contains(e)
- Container construction:
  - **query** (Set.contains(**int** x)): ...
  - **query** (Array[x] == **float** f): ...
  - **query** (Map.get(String s) == **int** i [**default** v]): ...
- **reduce**(sumInt) **int** x [**over** y]: ...

MORE PQL EXAMPLES

```
assert forall Node n: sorted_list.contains(n)
        -> n.prev.value <= n.value;
```

MORE PQL EXAMPLES

- Check sortedness of list

MORE PQL EXAMPLES

- Check sortedness of list

```
Set<Item> intersection =
        query (Set.get(Item element)):
                set0.contains(element)
            && set1.contains(element)
            && !element.is_dead;
```

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering

```
query (Map.get(employee) == double bonus):
    employees.contains(employee)
     && bonus == employee.dept.bonus_factor
        * (reduce(sumDouble) v:
        exists Bonus b: employee.bonusSet.contains(b)
        && v == b.bonus_base);
```

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering
- Employee bonus table

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering
- Employee bonus table

```
dot_product = reduce(add) x over y: x == a[y] * b[y];
```

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering
- Employee bonus table
- Vector dot product

MORE PQL EXAMPLES

- Check sortedness of list
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- Employee bonus table
- Vector dot product

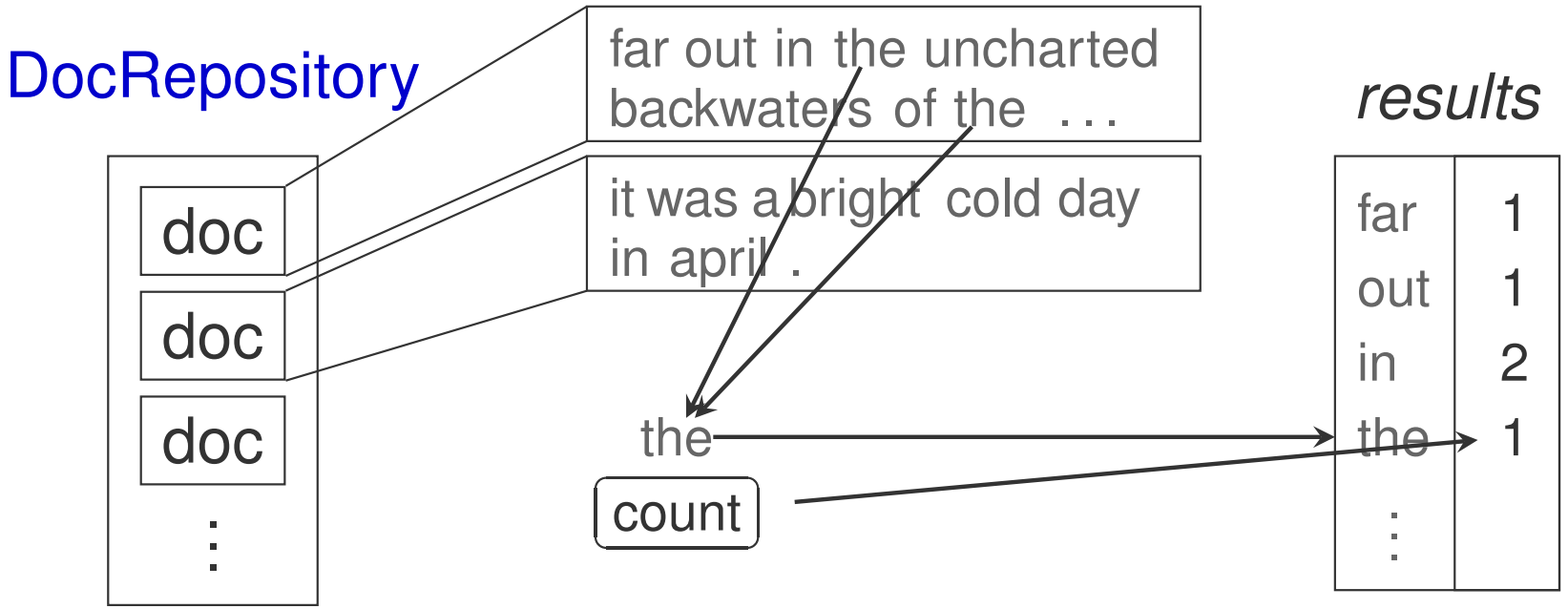
```
query (Map.find(value) == keyset default new PSet()):
    keyset == query (Set.contains(key)):
        m.get(key) == value;
```

MORE PQL EXAMPLES

- Check sortedness of list
- Set intersection together with filtering
- Employee bonus table
- Vector dot product
- Invert map

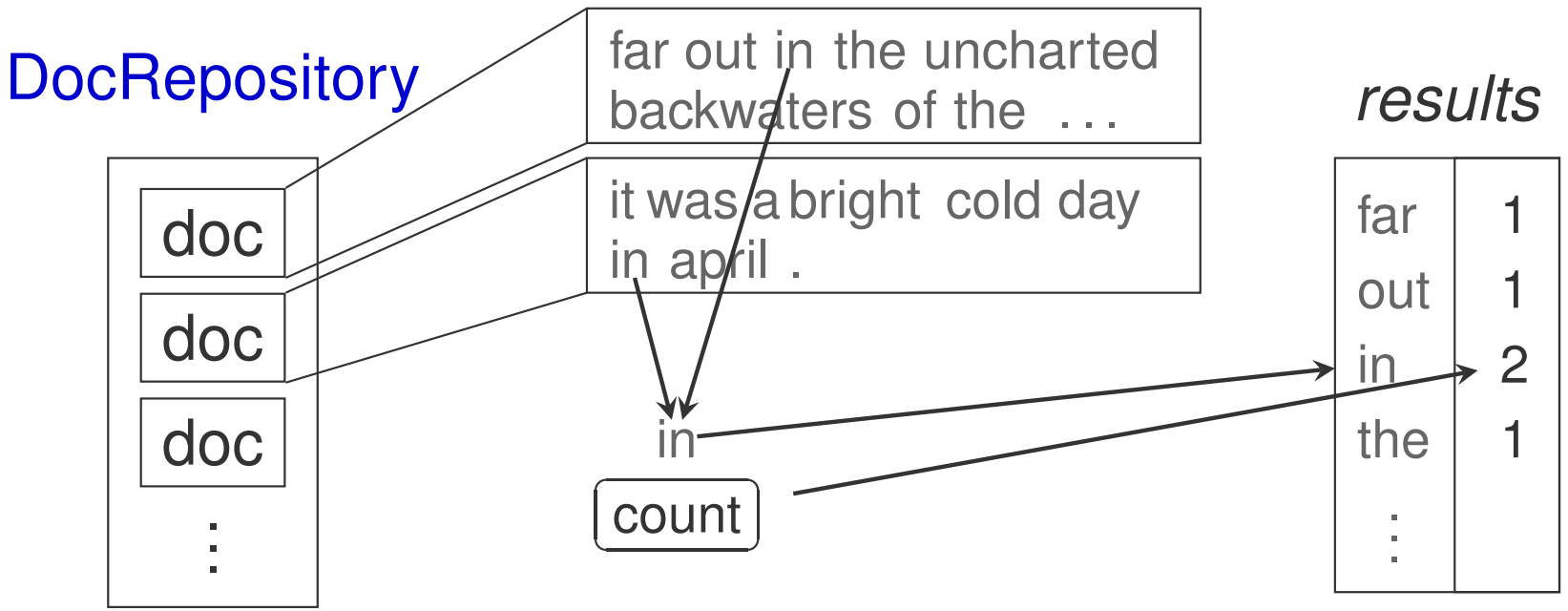
  . . .

REALISTIC PQL EXAMPLE



DocRepository.getAll().contains(doc)

REALISTIC PQL EXAMPLE



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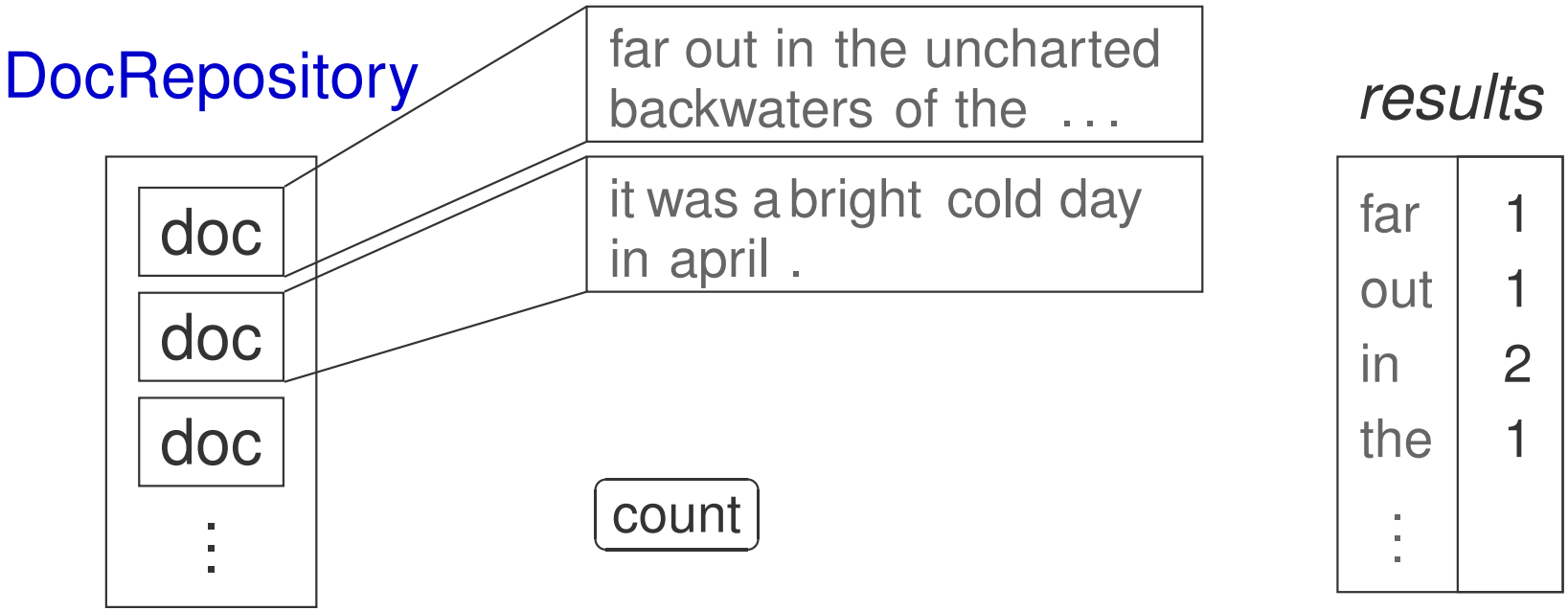
REALISTIC PQL EXAMPLE

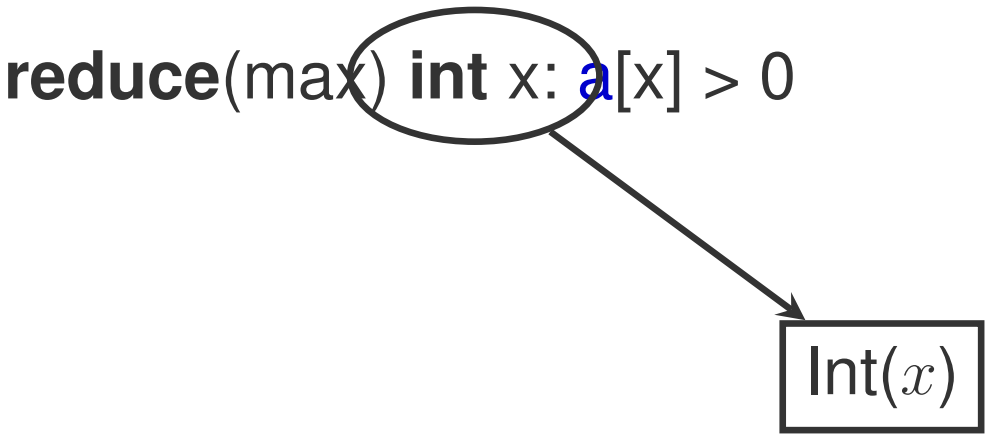



```
query (Map.get(int word_id) == int wcount default 0):
    wcount == reduce(sum) 1 over doc:
    DocRepository.getAll().contains(doc)
    && exists i: doc.words[i] == word_id;
```

IMPLEMENTATION

- Extension to javac 1.6:
  - PQL to relations
  - Access path selection / Query scheduling
  - Optimisation
  - Code generation
- Run-time library support:
  - parallel execution

EXAMPLE



Gen. relational IL

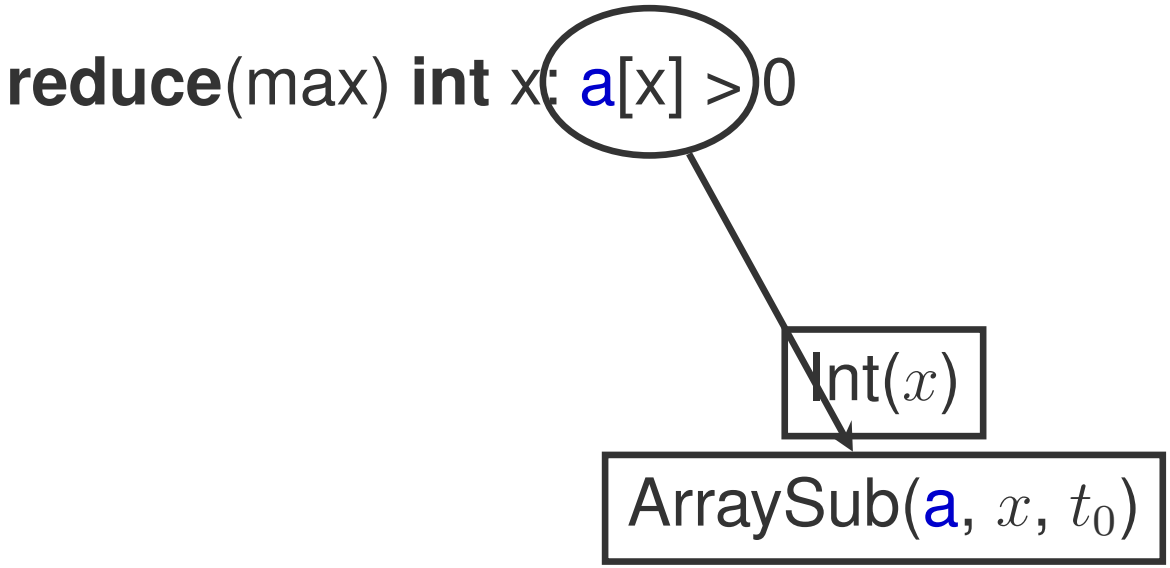
Query ordering

Optimisation

Code generation

Translation into relational IL

EXAMPLE



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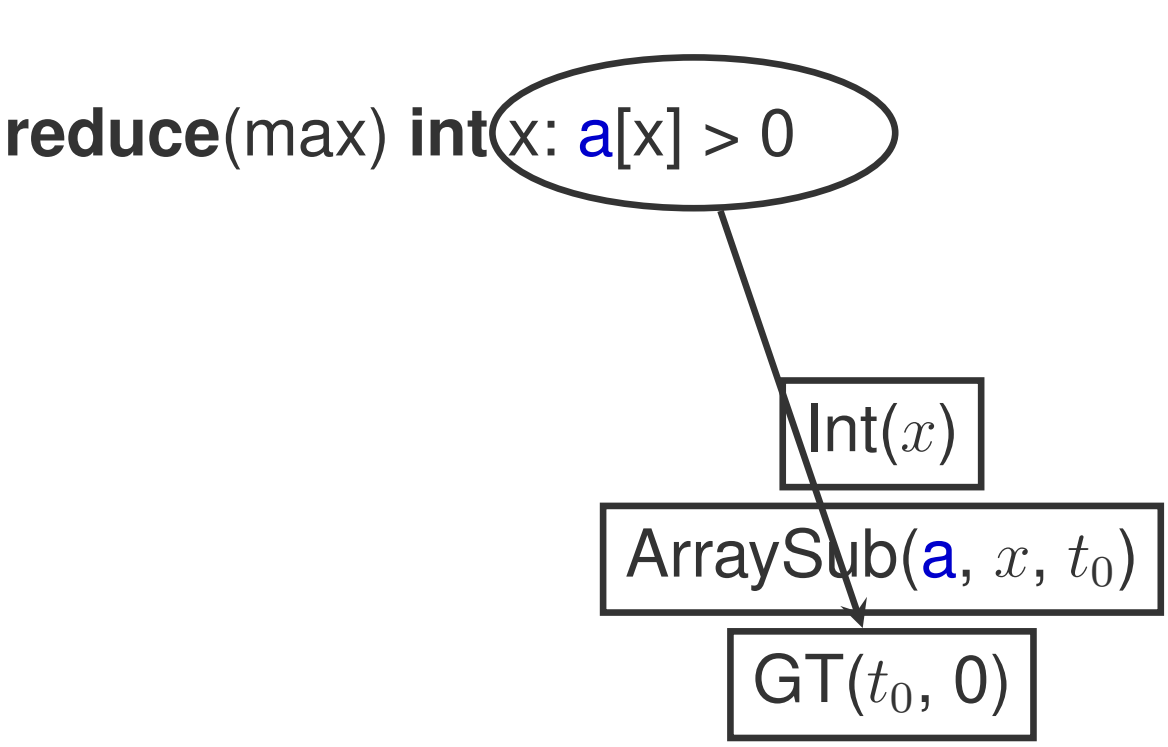

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EXAMPLE

reduce(max) **int** x: a[x] > 0

Gen. relational IL

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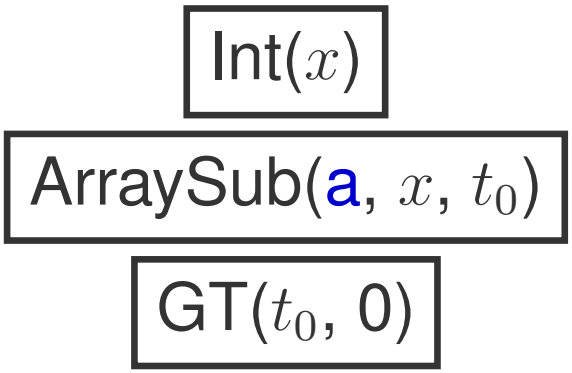

Unordered!

EXAMPLE

reduce(max) **int** x: a[x] > 0

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Int($x^{\mathbf{w}}$)

ArraySub(a$^{\mathbf{r}}$, $x^{\mathbf{r}}$, $t_0{}^{\mathbf{w}}$)

GT($t_0{}^{\mathbf{r}}$, 0)

Order #1: Must iterate over 2^{32} values!

EXAMPLE

reduce(max) **int** x: a[x] > 0

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Query ordering

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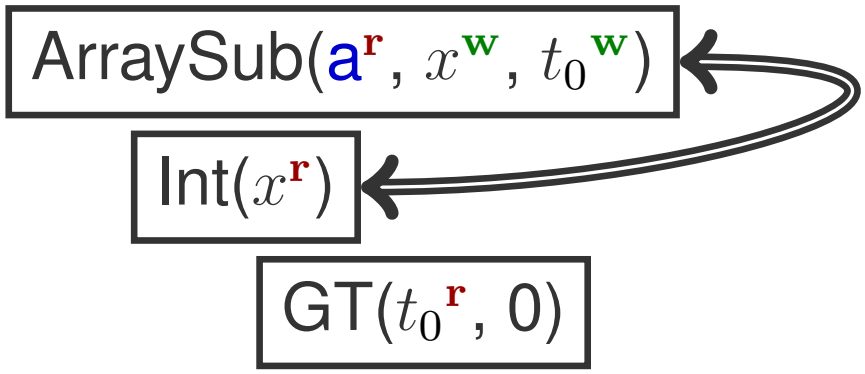

Order #2: Iterate over a.length values

EXAMPLE

reduce(max) **int** x: a[x] > 0

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Query ordering

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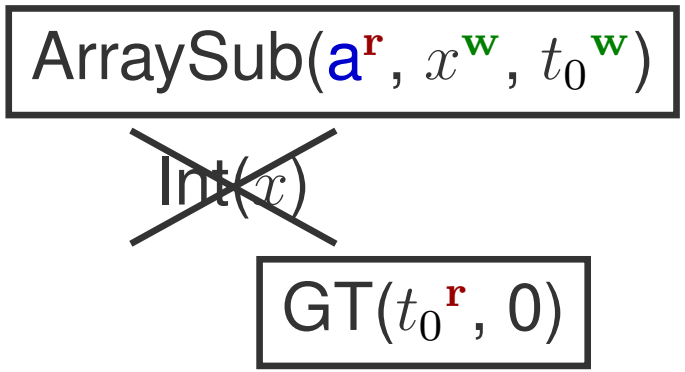


EXAMPLE

Gen. relational IL

Query ordering

Optimisation

Code generation

```
for (x = 0; x < a.length; x++) {
   t_0 = a[x];
      if (t_0 > 0)
            // signal success at x
}
```

EXAMPLE

Gen. relational IL

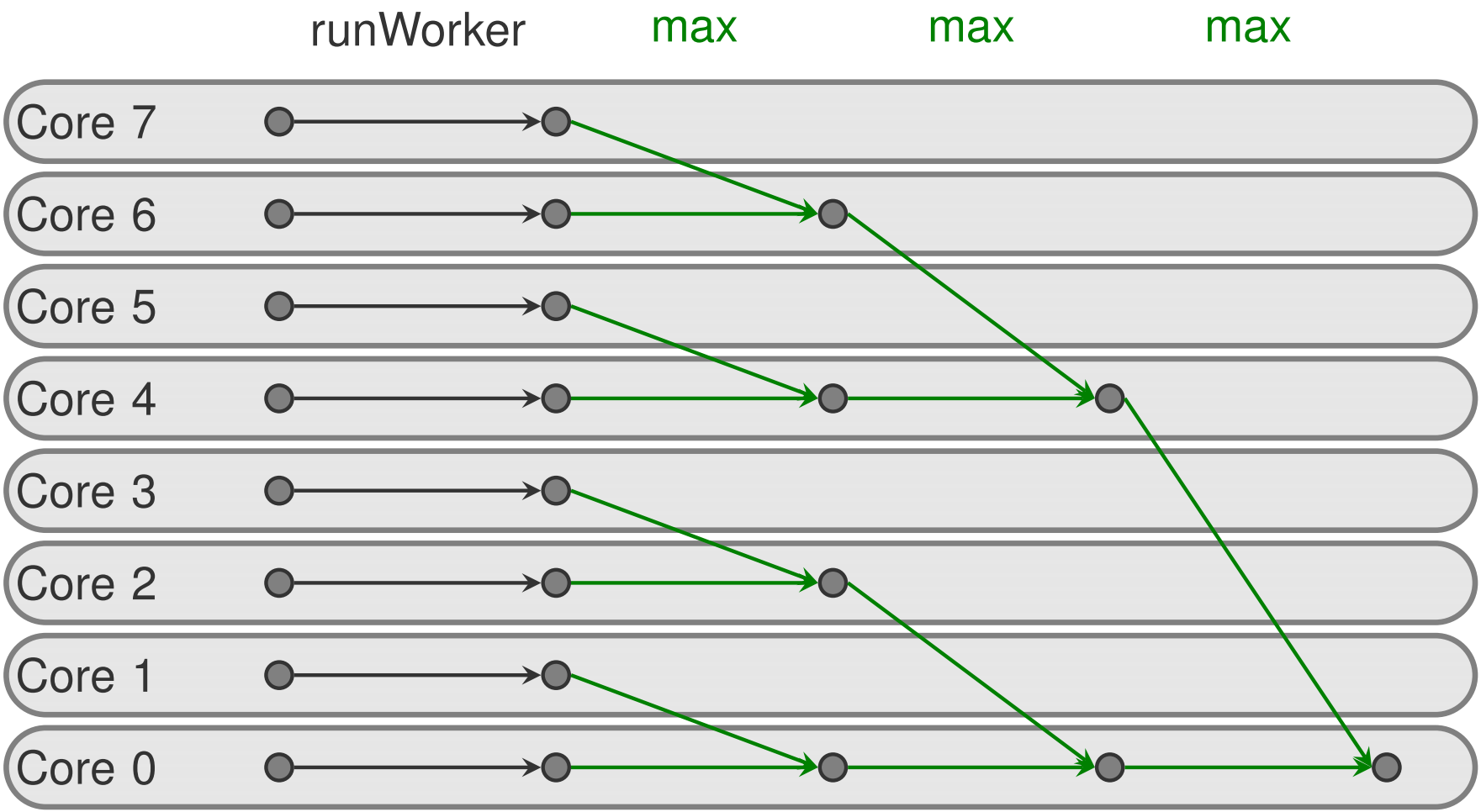
Query ordering

Optimisation

Code generation

```
void runWorker(int start, int stop) {
    for (x = start; x < stop; x++) {
      t_0 = a[x];
        if (t_0 > 0)
            // signal success at x
    } }
```

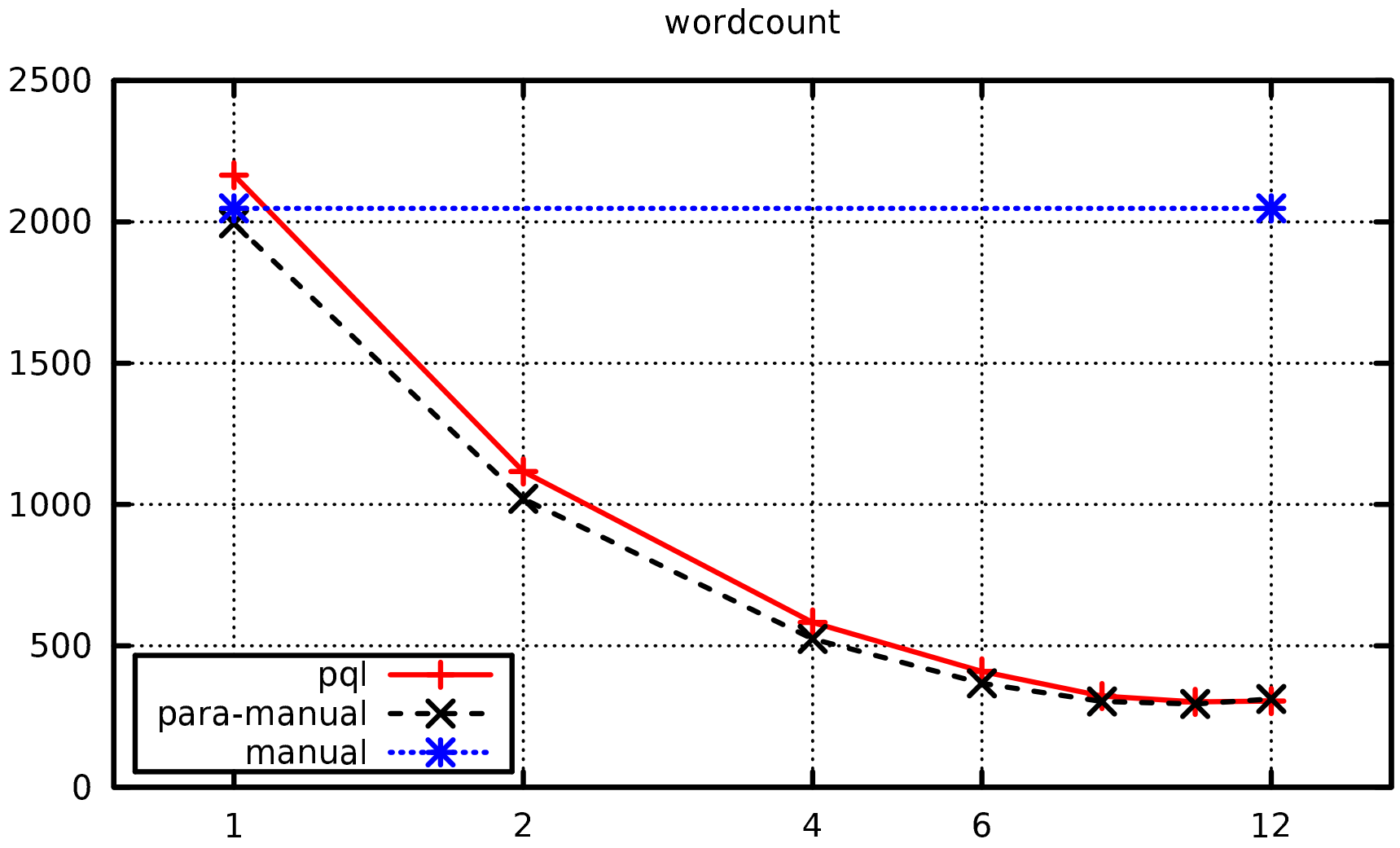
PARALLEL EXECUTION MODEL: TREE JOIN



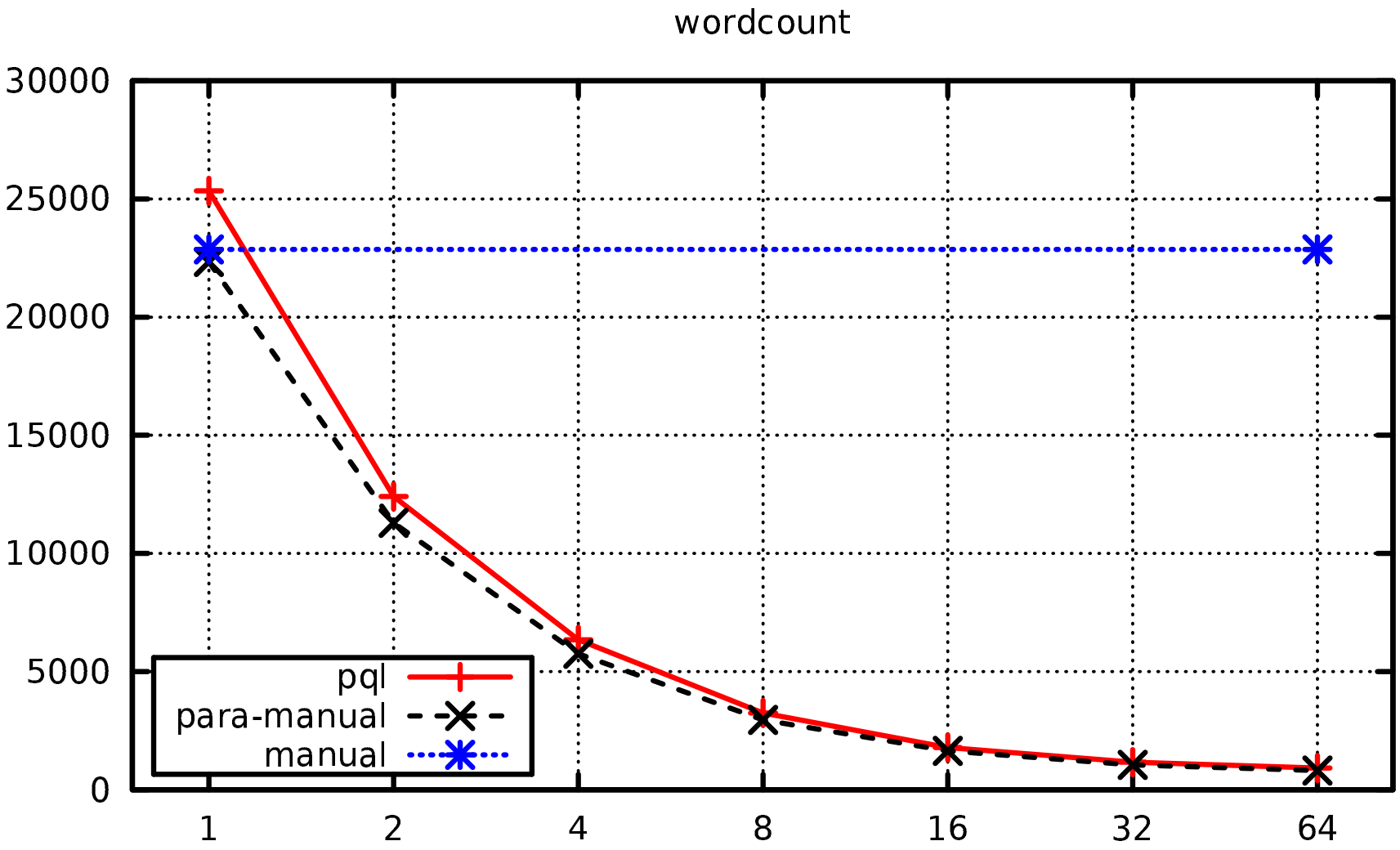
PERFORMANCE

- Benchmarks:
  - **bonus**: Salary computation
  - **threegrep**: String pattern search
  - **wordcount**: Word frequency aggregation in documents
  - **webgraph**: One-hop self-references in web graphs
- Hardware:
  - Intel Xeon 6×2 threads, 2.67 GHz, 24 GB RAM
  - Sun UltraSPARC 16×4 threads, 1.17 GHz, 32 GB RAM
- Methodology:
  - For each configuration: 3 warmup runs, 10 eval runs
- Running stock Sun JVM 1.6 with 2 GB Heap

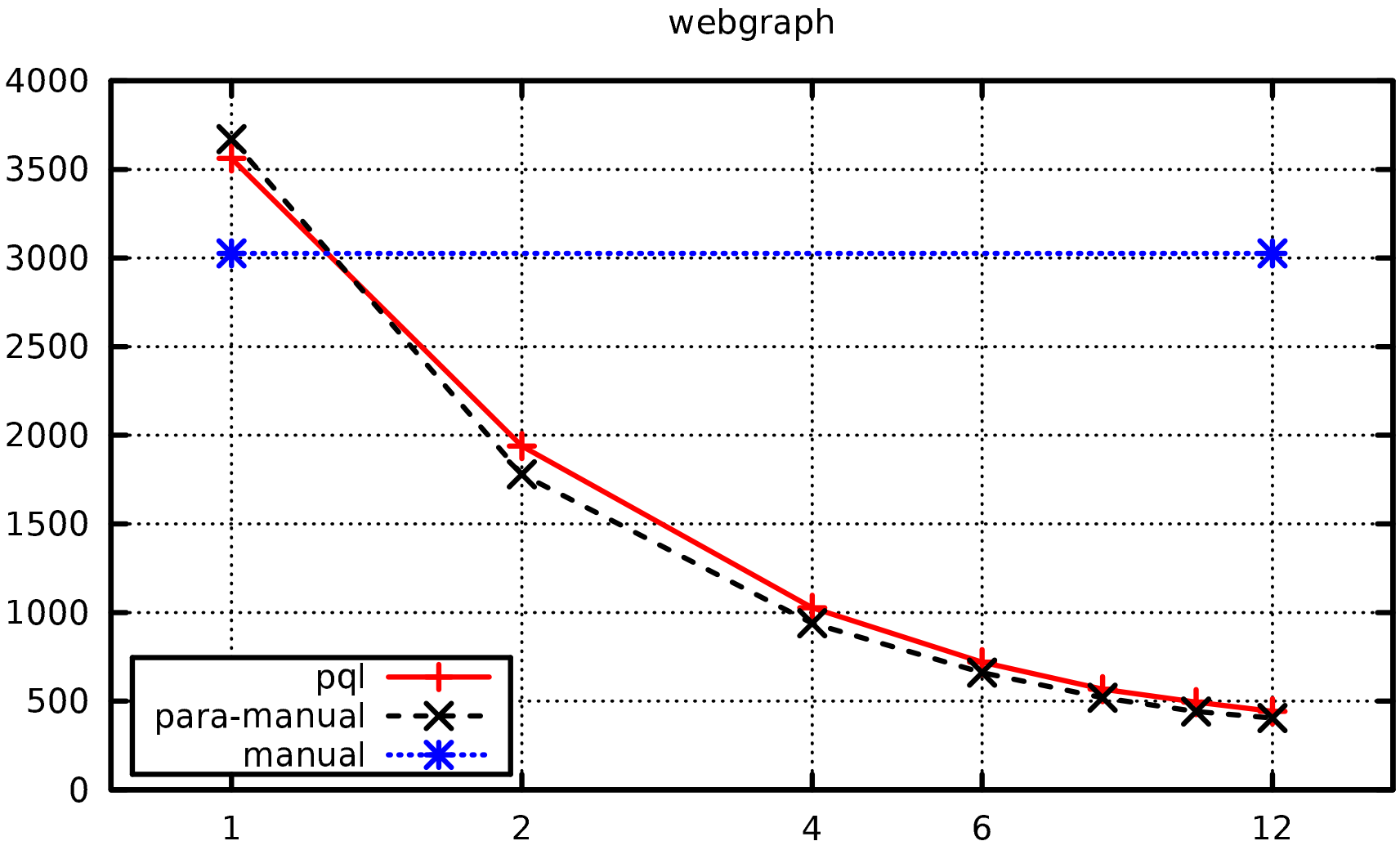
Performance results: Wordcount on Intel Xeon



PERFORMANCE RESULTS: WORDCOUNT ON ULTRASPARC



PERFORMANCE RESULTS: WEBGRAPH ON INTEL XEON



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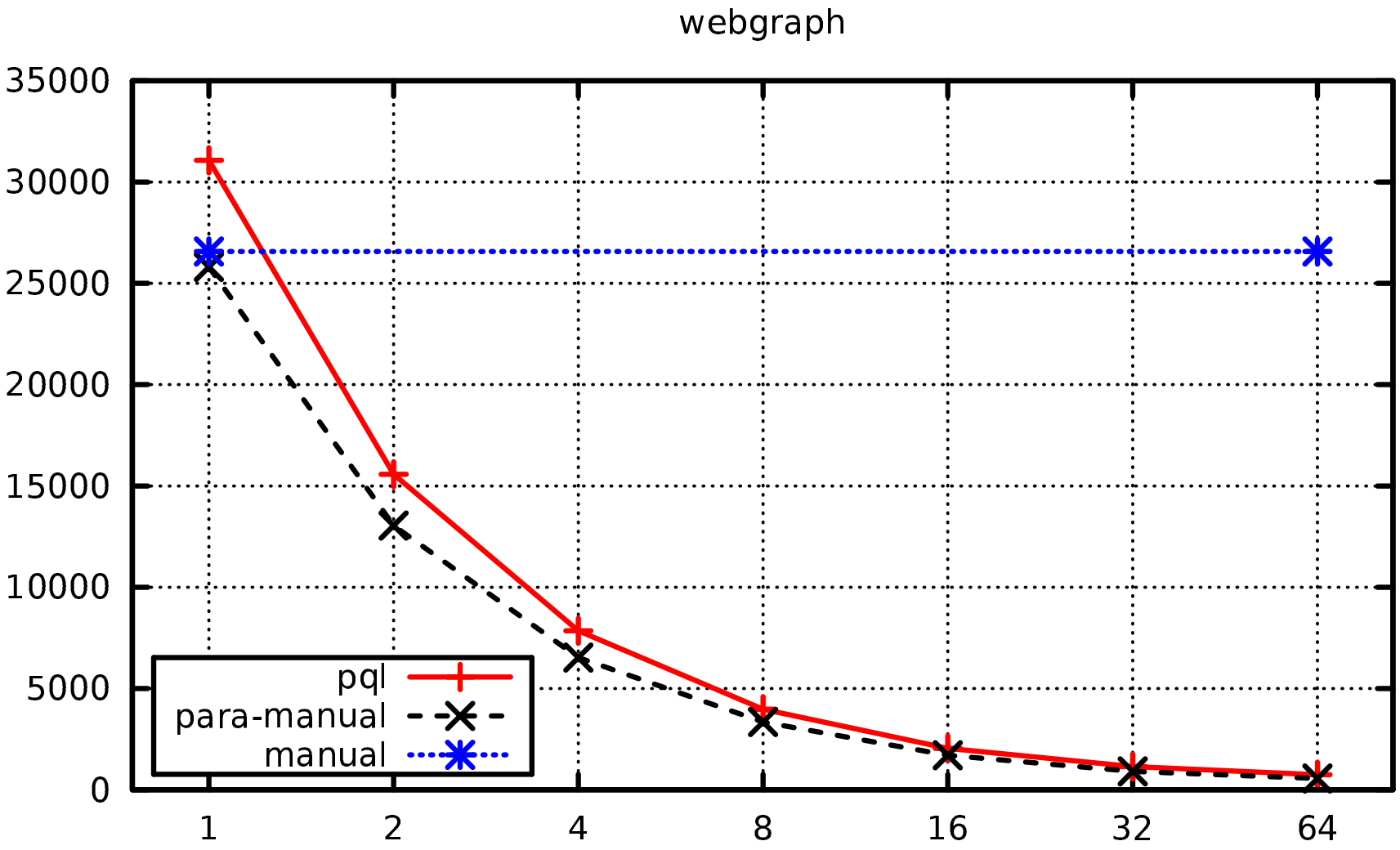

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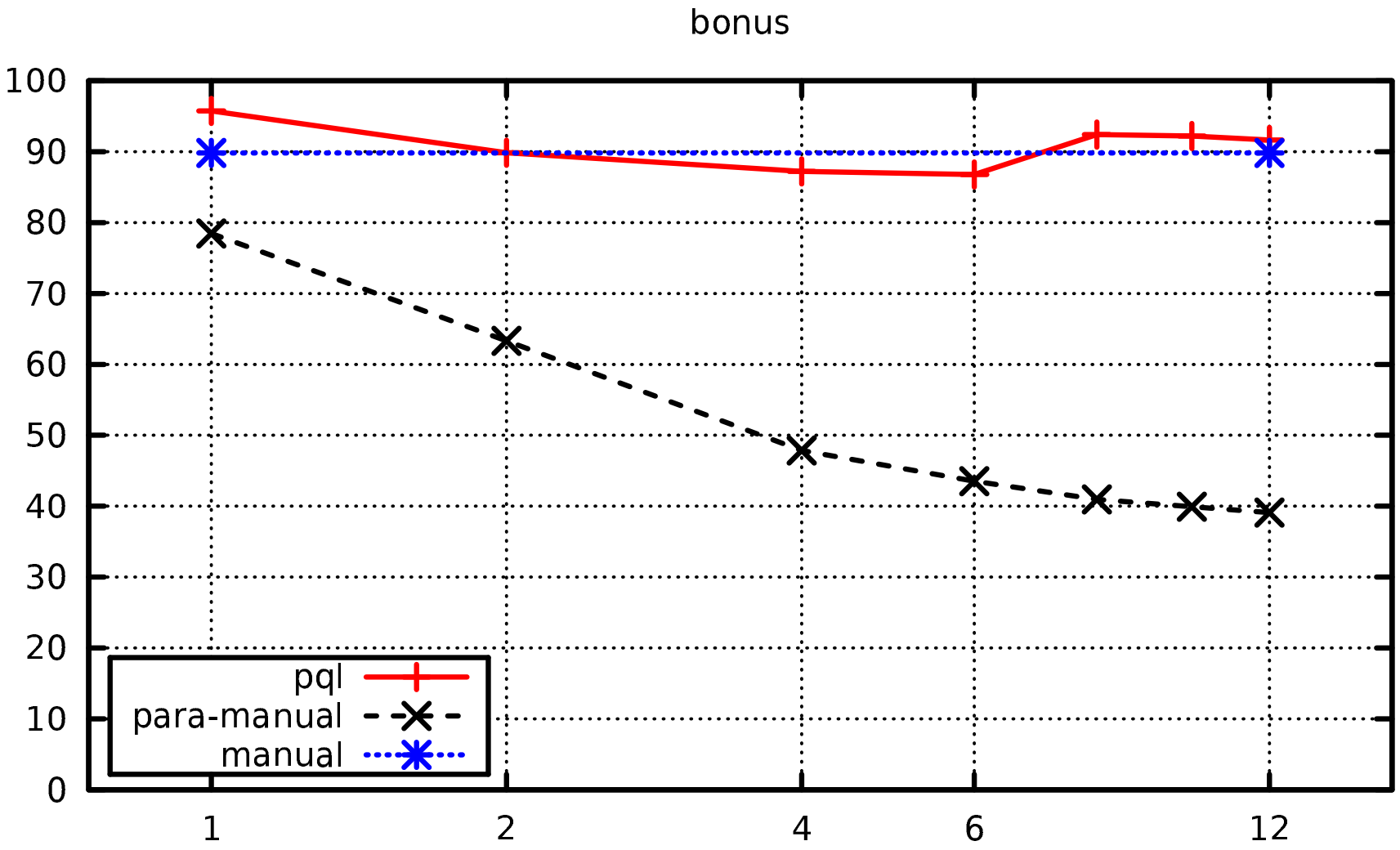
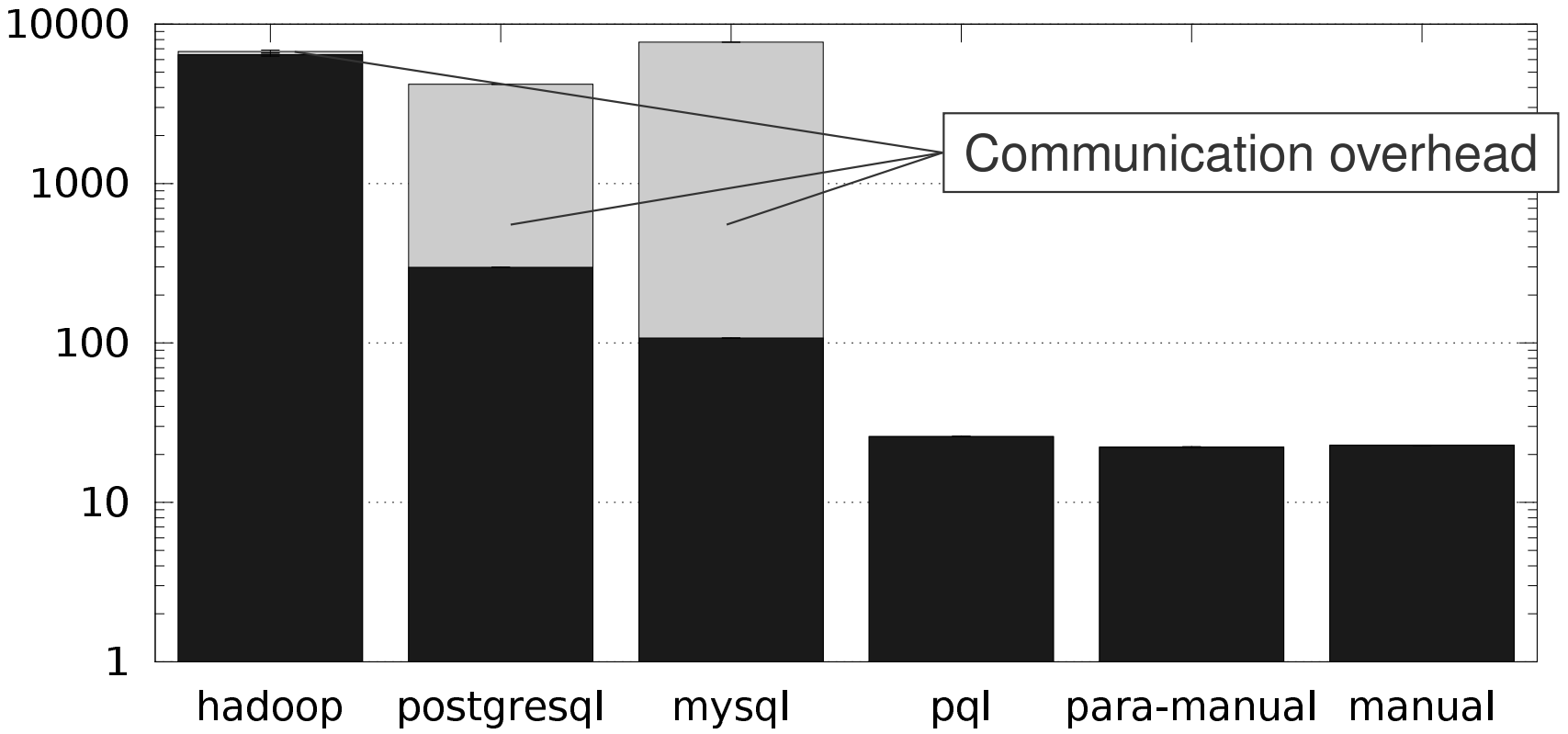


EXISTING APPROACHES FOR JAVA

- SQL via JDBC: Similar queries, separate heap
- Hadoop: Java Map-Reduce framework

COMPARISON TO SQL AND HADOOP



(At $\frac{1}{10}$ of the usual benchmark size)

CONCISENESS

Total lines of code (including Java boilerplate):

benchmark	manual	manual- parallel	Hadoop	SQL	PQL
bonus	9	50	130	48	8
threegrep	9	46	60	21	6
webgraph	13	50	105	39	4
wordcount	8	98	93	38	4

PQL implementations are concise

WHAT THIS TALK DIDN'T COVER

- Intermediate language design
- Type inference
- Domain inference:
  forall x: a[x] == b[x]: which x to check?
- More optimisations

Check the paper for details!

SUMMARY

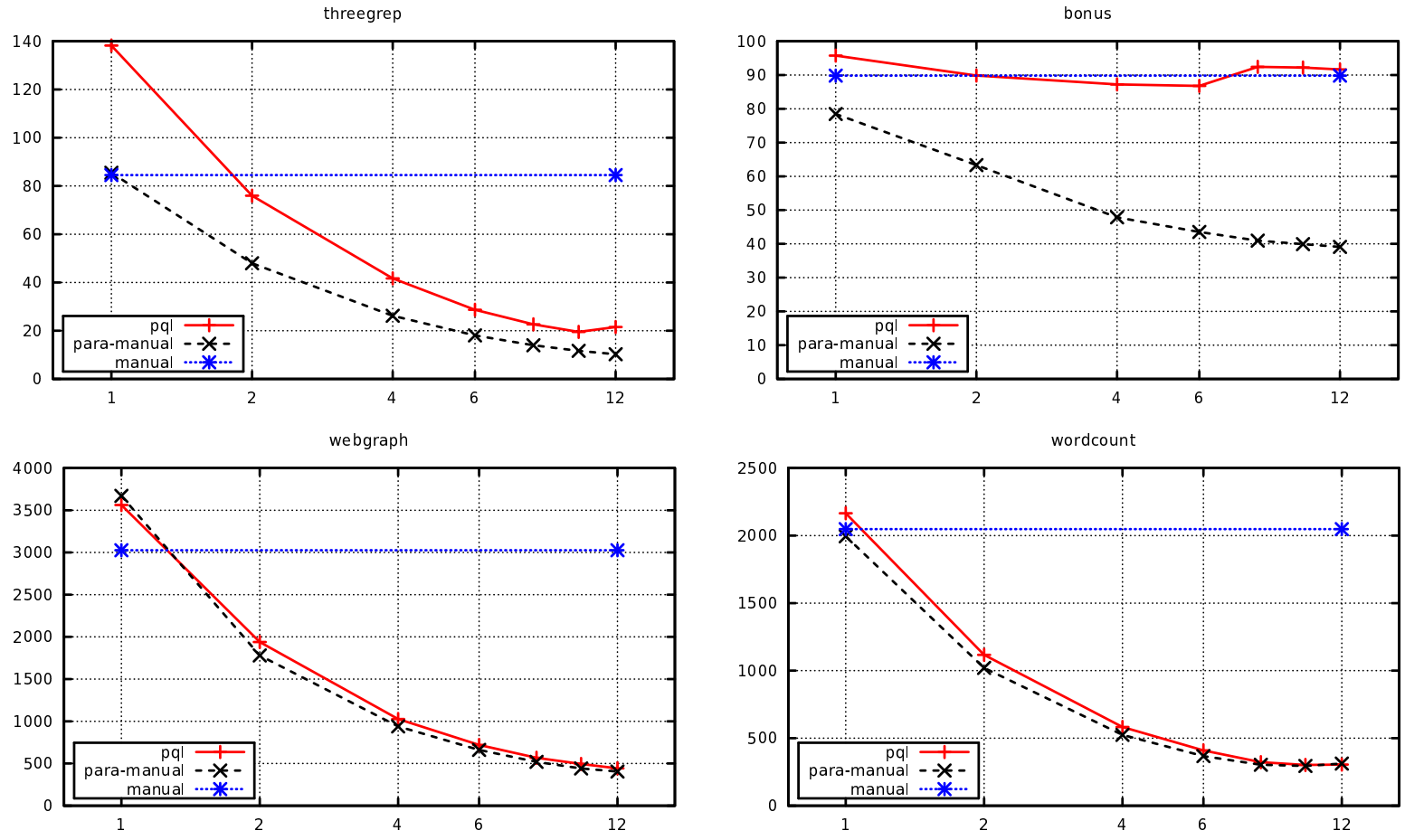
PQL/Java adds casual parallelism to Java through:

- Declarative query semantics
- Automatic parallelisation
- Strong parallel performance

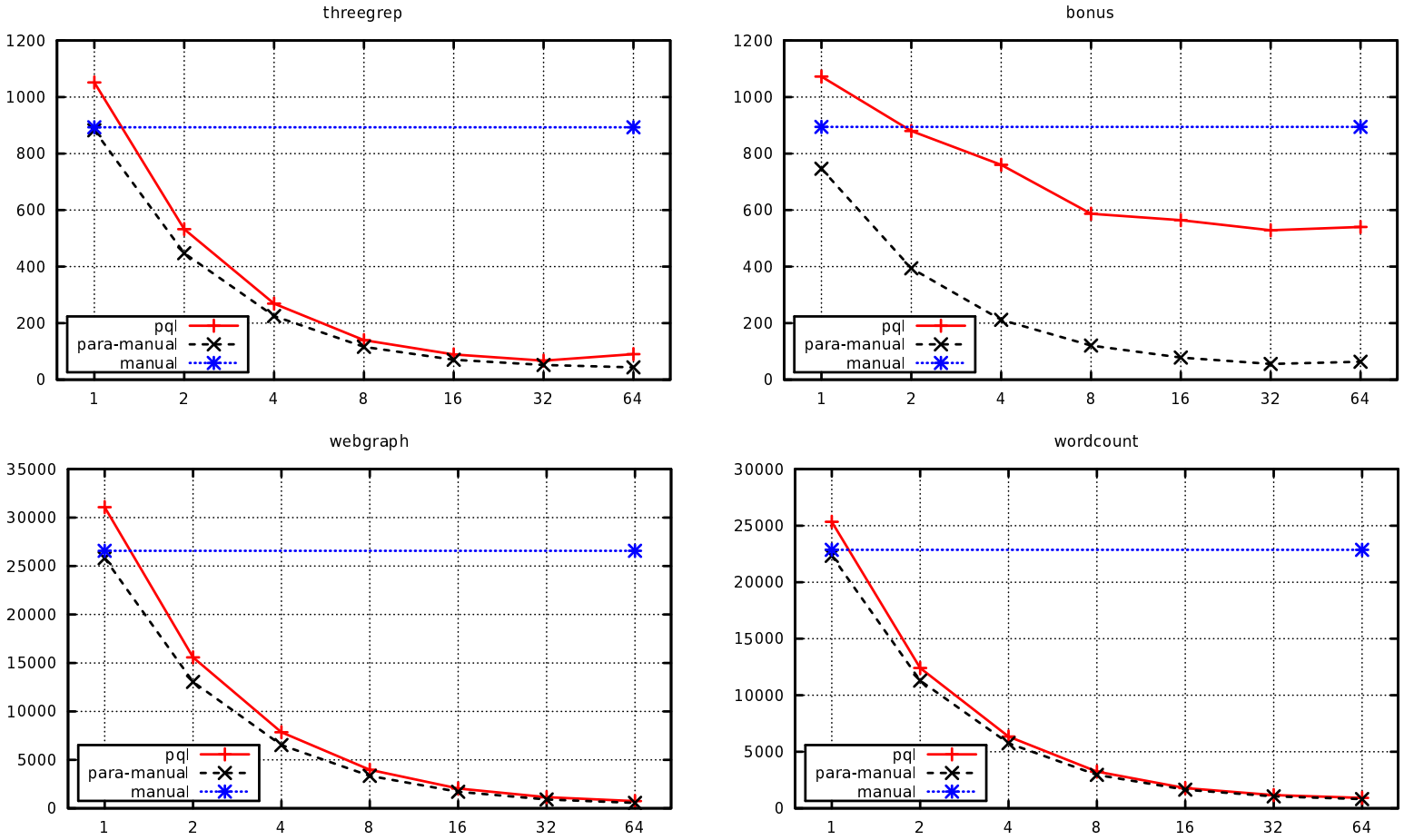
Available at `http://creichen.net/pql` (soon!)

Backup Slides

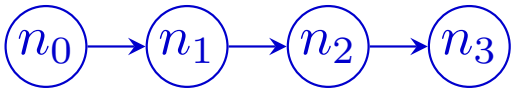
PERFORMANCE RESULTS: INTEL



PERFORMANCE RESULTS: SPARC



JAVA INTEGRATION: GRAPH REACHABILITY




```
new_edges = query(Map.find(from_node) == to_node):
    !all_edges[from_node].contains(to_node) // new edge
    && exists Node inter_node:
        all_edges[from_node].contains(inter_node)
        && new_edges[inter_node].contains(to_node);
```

JAVA INTEGRATION: GRAPH REACHABILITY

```
public Map<Node, Set<Node>> transitiveClosure(Map edges) {
  Map<Node, Set<Node>> all_edges = edges.clone();
  Map<Node, Set<Node>> new_edges = edges;
  while (!new_edges.empty()) {
    new_edges = query(Map.find(from_node) == to_node):
        !all_edges[from_node].contains(to_node) // new edge
        && exists Node inter_node:
            all_edges[from_node].contains(inter_node)
            && new_edges[inter_node].contains(to_node);
    all_edges.putAll(new_edges);
  }
  return all_edges; }
```