# *Deterministic Parallel Java:* Towards Deterministic-by-Default Parallel Programming

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# Proposal

**Parallel languages should be *deterministic by default***

**I.e., Determinism should be *guaranteed* unless non-determinism is requested explicitly**

**Deterministic semantics:**

1. Fixed input gives unique output (up to acceptable precision)
2. Obvious sequential equivalent

# Deterministic Parallel Java: Project Overview

## Explicitly parallel, deterministic-by-default, language

- Novel region-based type and effect system
- Today: No run-time checks; may add them in future

## Enforces safe *use* of parallel frameworks

- Enforce safety requirements on client code

## Disciplined support for non-deterministic code

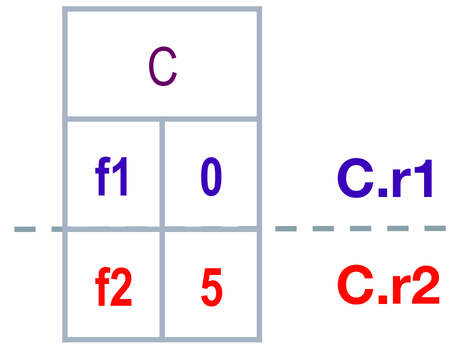
- Explicit; data race free; isolated

## DPJizer: Interactive porting environment

- Eclipse plug-in to infer DPJ annotations

# Example: Regions and Effects

```
class C {
region r1, r2;
int f1 in r1;
int f2 in r2;
void m1(int x) writes r1 { f1 = x; }
void m2(int y) writes r2 { f2 = y; }
void m3(int x, int y) {
        cobegin {
           m1(x);
           m2(y);
        }
}
}
```




**Partitioning the heap**

# Example:  Regions and Effects

```
class C {
region r1, r2;
int f1 in r1;
int f2 in r2;
void m1(int x) writes r1 { f1 = x; }
void m2(int y) writes r2 { f2 = y; }
void m3(int x, int y) {
        cobegin {
            m1(x);
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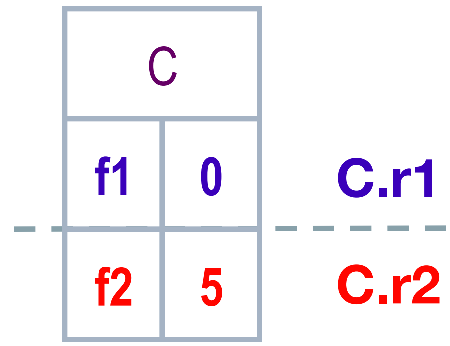


**Summarizing method effects**

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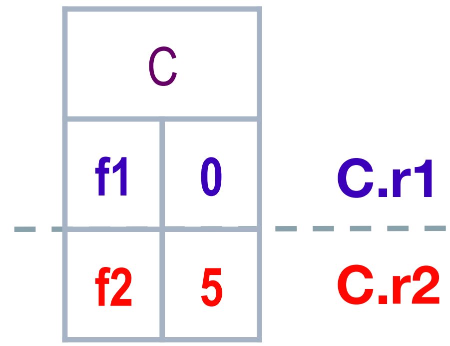
# Example: Regions and Effects

```
class C {
region r1, r2;
int f1 in r1;
int f2 in r2;
void m1(int x) writes r1 { f1 = x; }
void m2(int y) writes r2 { f2 = y; }
void m3(int x, int y) {
        cobegin {
            m1(x); // Inferred effect = writes r1
            m2(y); // Inferred effect = writes r2
        }
}
}
```




**Expressing parallelism**

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# Supporting Parallel Patterns

**DPJ uses novel features to support parallel codes**

- Parallel operations on arrays of references
- Divide and conquer on nested structures
- Divide and conquer operations on arrays
- Commutative operations

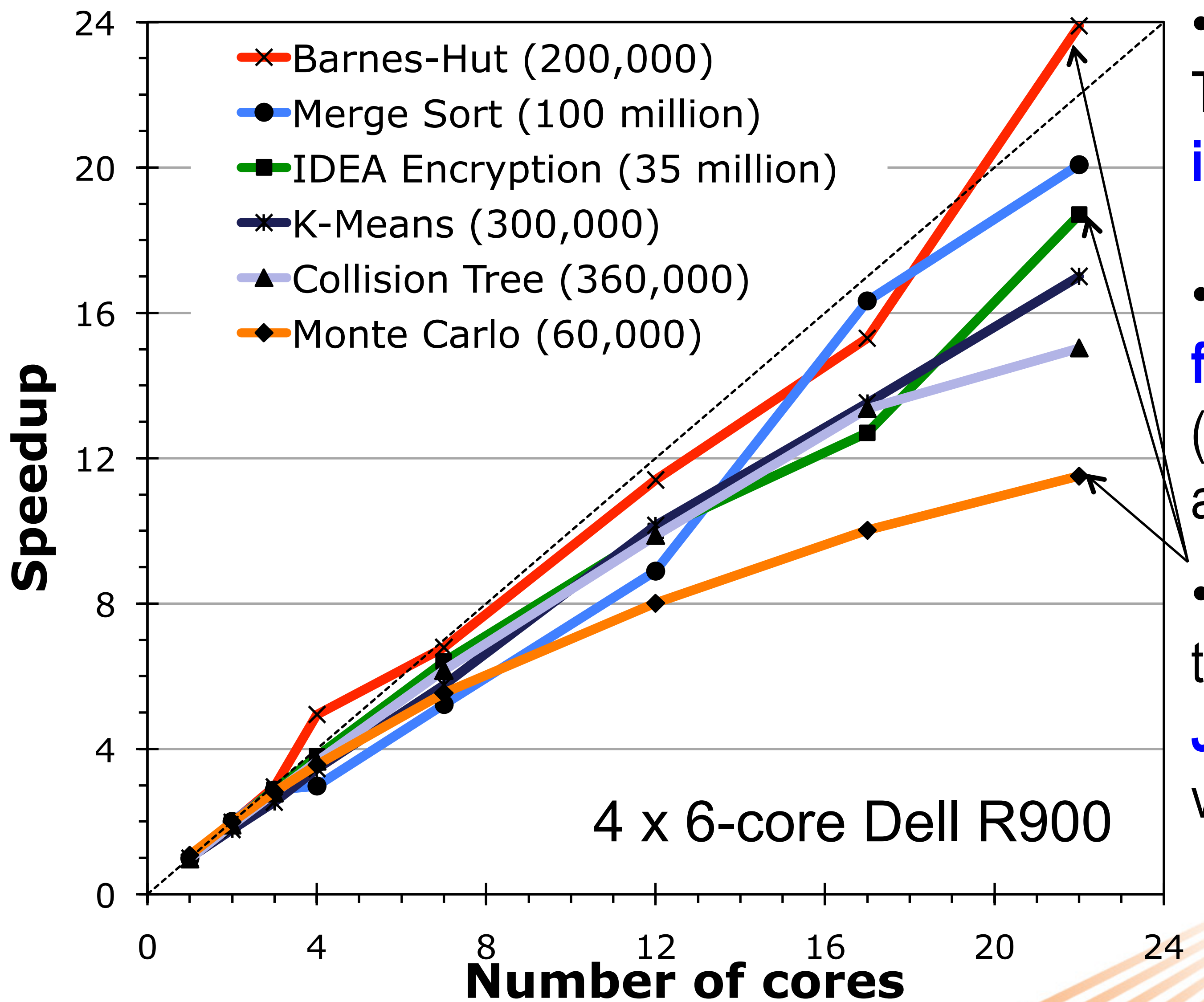
**Formalism**

- Type system
- Proof of *non-interference* for all legal programs



*See OOPSLA 2009 paper for details*

# Performance Evaluation




- B-H, Collision Tree are **highly irregular**
- DPJ **expresses full parallelism** (except SIMD) in all but B-H
- Close to or better than hand-tuned **Java threads** versions

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# Analysis

## Strengths

+ Captures *all* non-SIMD parallelism in all but Barnes Hut
+ Introduces *no* inherent run-time overheads
+ Allows incremental porting (e.g., JMonkey), tuning

## Weaknesses

- Cannot express some idioms
  - E.g., array reshuffling (Barnes Hut), tree rebalancing
- Some DPJ features can be complex or constraining
  - *Complex syntax*: Index-parameterized arrays
  - *Constraining*: Superclass method's effects must be a superset of any subclass method's effects

# Parallel Frameworks

## Valuable For Parallel Computing …

- Division of labor: parallelism experts vs. users
- Easy for user (write sequential code)
- Many real world (parallel) examples exist
  - MapReduce; `ParallelArray`; Algorithm templates (TBB)

## … And Address a Key DPJ Limitation

- Idioms that cannot be checked by type system

## … But Challenging

- User must follow many unchecked safety rules
- Must be easily extensible

# Support for Frameworks in DPJ

*Idea 1*: Enable *design by contract* for framework APIs

- ➢ Not been done before for shared memory parallelism

*Idea 2*: Check framework *internals* via other means but hook into the type system

- ➢ Testing, program verification, etc.

We show how to …

- ➢ Use DPJ "off the shelf" to write safe container APIs
  - Constrain aliasing and effects
- ➢ Allow greater flexibility via generic types and effects
  - Effect variables, type region parameters
- ➢ Make different forms of verification interoperate
  - Type system uses two predicates: *disjoint-rgn, disjoint-ref*
  - These predicates must be discharged externally

# Writing Realistic Frameworks

- **Array: safe wrapper around Java `ParallelArray`**
  - **Operations: create(), withMapping(), reduce()**
  - **Example client: *Monte Carlo* (Java Grande)**
- **Tree (from scratch, inspired by tree algorithms)**
  - **Operations: buildTree(), visitPO()**
  - **Example client: *Barnes-Hut center of mass***
- **Experience**
  - Safe frameworks express algorithms well
  - Writing API is sometimes tricky but client code is simple
    - **`pure` or one or two *extra* read effects**
  - More flexible: e.g., reordering array; rebalancing tree

# Non-deterministic Parallelism

## Numerous non-deterministic algorithms, programs

- Branch-and-bound optimization, e.g., for TSP
- Clustering algorithms
- Delaunay mesh refinement
- Servers with transactional parallelism
- …

## Common Feature

- Non-commutative parallel updates
- Synchronized for atomicity (not ordering)

# Example: Writing TSP in DPJ

Non-determinism must be explicit

atomic *statement* synchronizes conflicting accesses

```
foreach_nd (int i in 0, Nworkers-1) {
  atomic {
    remove path-prefix pfx from pq;
    if (pfx is long enough) return pfx;
    extend pfx and insert in pq;
  }
  for (each Hamiltonian cycle with prefix pfx) {
    atomic {
     if (tour.length() < bestTour.length())
      bestTour = tour;
    }
  }
}
```

Conflicting operations must appear in atomic

# Safety Guarantees for Non-determinism

- Program is data-race free
- Execution is serialization of
  (a) `foreach`; (b) `cobegin`; (c) `atomic`; (d) reads/writes outside these
- `foreach,cobegin` retain most of their guarantees
  - Can reason about them in isolation
  - Retain sequential equivalence
  - Retain input-output determinism *if* they do not enclose foreach_nd or cobegin_nd

# Summary

## DPJ today: strong semantic guarantees

- Deterministic semantics *unless* explicitly requested otherwise
- Through simple compile-time type checking
- Safe use of parallel frameworks
- Non-deterministic code is (a) explicit; (b) data race free; (c) explicit

## Future work: ease of adoption

- Extend to C++
- DPJizer: Interactive porting tool
- Experience with real world software

See *dpj.cs.uiuc.edu* for references.

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# Extra Slides