Habanero-Java Library: a Java 8 Framework for Multicore Programming

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Shams Imam, Vivek Sarkar
shams@rice.edu, vsarkar@rice.edu
Rice University

https://wiki.rice.edu/confluence/display/PARPROG/HJ+Library

Introduction

- Multicore processors are now ubiquitous
  - server, desktop, and laptop hardware
  - smaller devices: smartphones and tablets
- Parallelism is the future of computing
- Introduce parallelism early into the Computer Science curriculum

Motivation for HJlib

- Writing parallel programs is hard
- Programmers need higher level parallel programming
- Distinguish between parallelism and concurrency
- Language approach requires extensions
  - Special compiler support
- Library-based approach integrates easily with existing code
  - Users can use IDE and tools of choice
  - Java 8 provides an excellent foundation for rich library support for parallelism and concurrency

Contributions of this paper

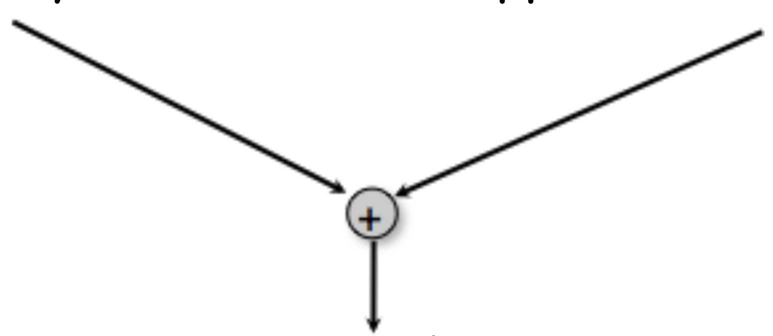
- Habanero-Java library (HJlib) - a pure Java 8 library implementation of a multi-faceted task-parallel programming model
- `EventDrivenControl` API which can be used to add new parallel constructs to HJlib
  - All existing HJlib synchronization constructs (e.g., futures, data-driven futures, phasers) are also built using this API
  - Automatic support for AEM and deadlock detection
- Abstract Execution Metrics (AEM) framework for HJlib
- Deadlock detection tool for HJlib

Simple Example: Two-way Parallel Array Sum

- Basic idea:
  - Decompose problem into two tasks for partial sums
  - Combine results to obtain final answer
  - Parallel divide-and-conquer pattern

Task 0: Compute sum of lower half of array

Task 1: Compute sum of upper half of array



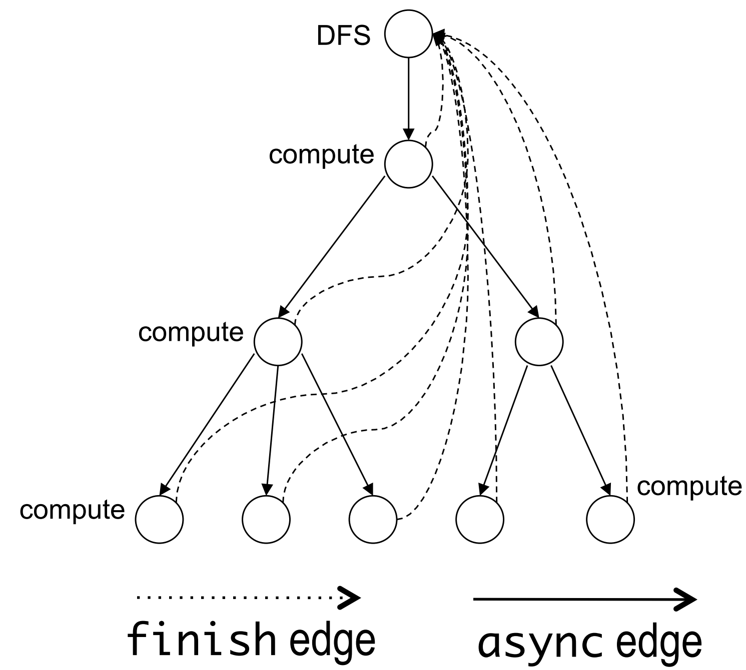
Compute total sum

Simple Example: Two-way Parallel Array Sum

```
// Start of Task T0 (main program)
sum1 = 0; sum2 = 0; // sum1 & sum2 are static fields
finish(() -> {
  async(() -> {
    // Child task computes sum of lower half of array
    for (int i=0; i < X.length/2; i++) sum1 += X[i];
  }); // end async
  // Parent task computes sum of upper half of array
  for (int i=X.length/2; i < X.length; i++) sum2 += X[i];
}); // end finish
// Parent task waits for child task to complete (join)
return sum1 + sum2;
```

More complex HJlib example: Parallel Spanning Tree

```
class V  {
  V [] neighbors; // Input adjacency list
  V parent; // Output spanning tree
  . . .
  boolean tryLabeling(final V n) {
   isolated(this, () -> {
     if (parent == null) parent = n;
   });
   return parent == n;
  } // end tryLabeling
  void compute() {
   for (int i=0; i<neighbors.length; i++) {
     final V child = neighbors[i];
     if (child.tryLabeling(this))
         //escaping async
         async(() -> { child.compute(); });
   }
  } // end compute
 } // end class V
 root.parent = root; // Use self-cycle to identify root
 finish(() -> { root.compute(); });
```



NOTE: this parallel structure cannot easily be expressed using standard Java constructs

HJlib Parallel Constructs

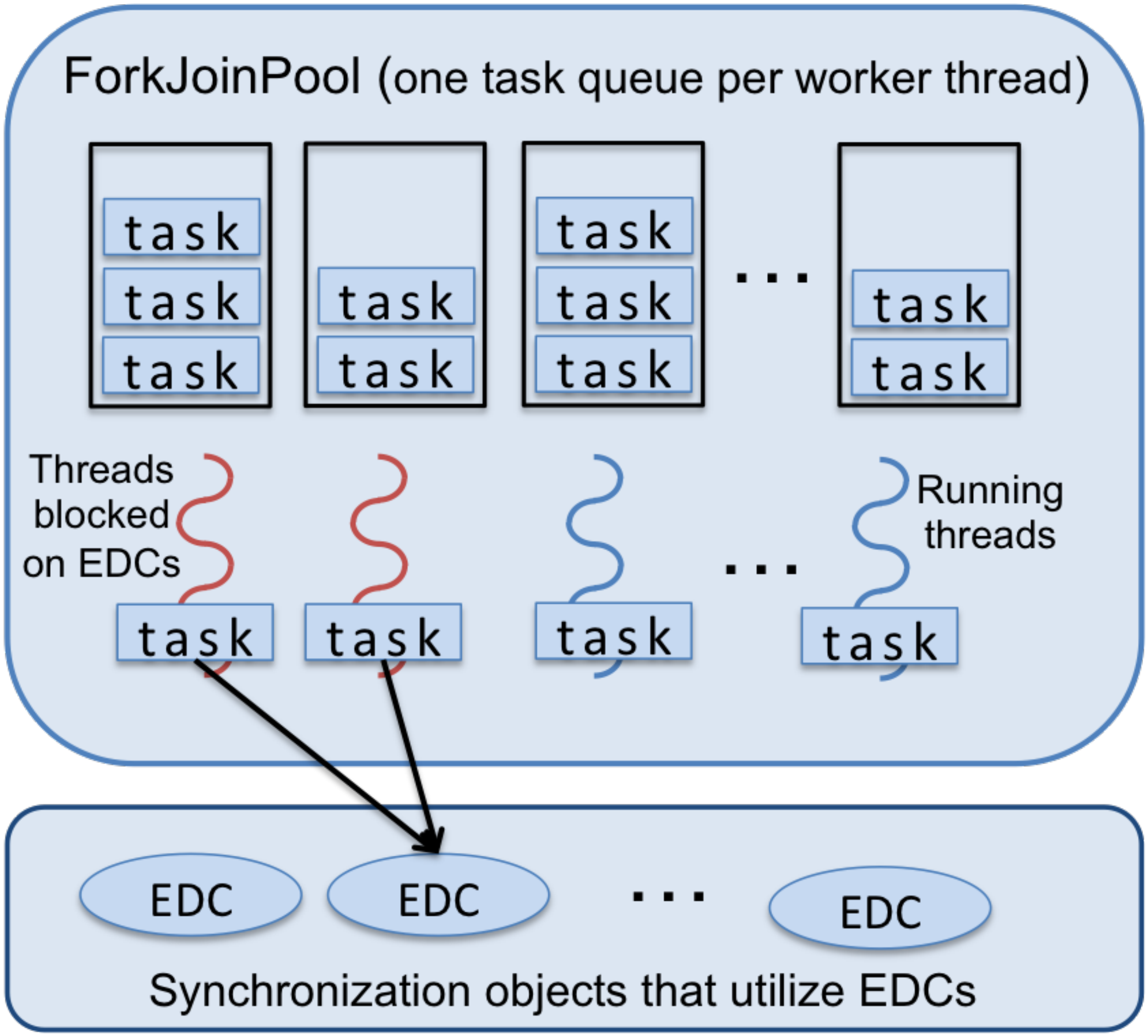
- Structured fork-join style parallelism (`async`/`finish`)
- Parallel loops (`forall`/`forasync`)
- Weak Atomicity (`isolated`)
- Task Dependencies (`DataDrivenFuture`)
- Point-2-Point Synchronization (`Phaser`)
- Parallel Reductions (`FinishAccumulator`)
- Asynchronous Message Passing (`Actor`)

- Summary: HJlib supports an explicit parallel programming model at a higher level of abstraction and a wider range of parallel constructs than standard Java

Implementation

- No external dependencies
- Build on the capabilities offered by the Fork/Join Framework
  - ForkJoinPool work-stealing scheduler in JDK
- Built using Java 8 features
  - Lambda expressions
  - Functional interfaces
  - Older JVMs can be targeted by bytecode transformations
- Publisher/Subscriber model in runtime to add additional features

Runtime Implementation



Default Runtime

- Default runtime uses work-first policy with ForkJoin framework
- Blocking conditions block worker threads
  - Scheduler spawns additional worker threads to compensate
  - Runtime executes ‘non-blocking’ tasks before blocking
- All synchronizations implemented using EventDrivenControl data structure
  - Tracks which threads are blocked or can be resumed
- NEW: Alternative cooperative runtime is also available for HJlib
  - Pro: worker threads never block
  - Con: current continuation support adds overhead due to use of exceptions and on-the-fly bytecode transformation in class loader

Event-Driven Control (EDC)

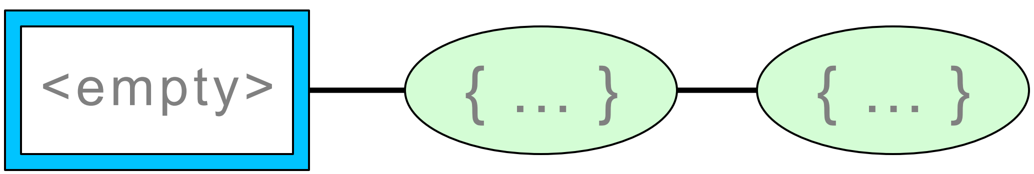
- Binds a value and a list of java.lang.Runnable blocks
  - Runnable blocks are code executed as callbacks
- Dynamic single-assignment of value (event)

<empty>

The EDC is initially empty

Event-Driven Control (EDC)

- Binds a value and a list of Runnable blocks
- Dynamic single-assignment of value (event)



Runnable blocks attach to the EDC and are not triggered until value is available (i.e. until event is satisfied)

Event-Driven Control (EDC)

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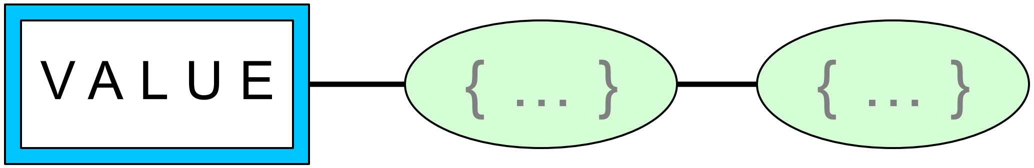

Eventually, a value becomes available in the EDC (follows from deadlock freedom property of finish, futures, clocks, atomic)

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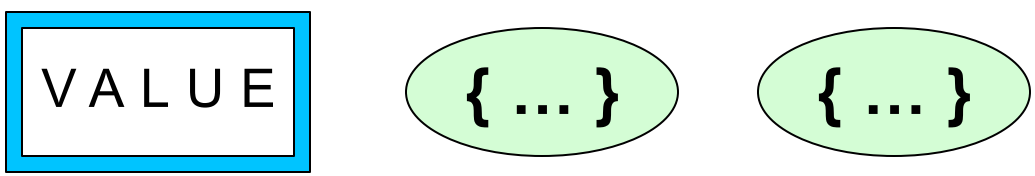

This enables execution of runnable blocks attached to the EDC

Event-Driven Control (EDC)

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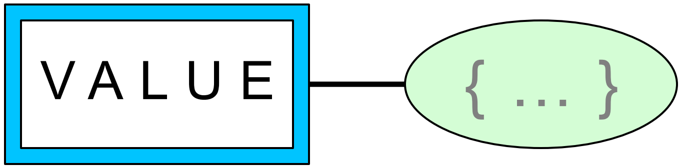

Once value is available, subsequent runnable block attachment requests…

Event-Driven Control (EDC)

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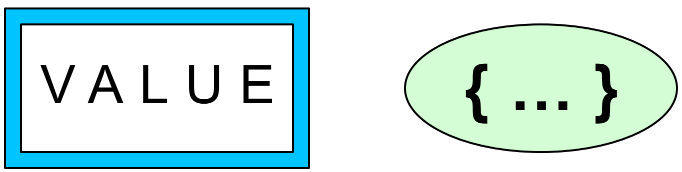
- Dynamic single-assignment of value (event)



Synchronously execute the block
(e.g. schedule a task into the work queue)

Event-Driven Control API

- `currentTaskId`():
  - returns a unique id of the currently executing task
- `newEDC`():
  - factory method to create EDC instance
- `suspend`(*anEdc*):
  - the current task is suspended if the EDC has not been resolved
  - Implementation attaches runnable block to resume task
- *anEdc*.`getValue`()
  - retrieves the value associated with the EDC
  - safe to call this method if execution proceeds past a call to `suspend`()
- *anEdc*.`setValue`(*aValue*)
  - resolves the EDC
  - triggers the execution of any EBs

Parallel Constructs in Runtime

- Any task-parallel Synchronization Constraint can be supported.
  - Both deterministic and non-deterministic constructs
- All HJlib parallel constructs implemented using EDCs and event listeners (publish/subscriber) attached to runtime
- Key idea is to:
  - Translate the coordination constraints into producer-consumer constraints on EDCs
  - Block/Suspend consumers when waiting on item(s) from producer(s)
- Developers can add their implement own parallel constructs and add to HJlib
  - E.g. EventCount, others noted in future work

Abstract Execution Metrics

- Enable users to reason about the performance of their parallel algorithms
- Compute total work done and critical path length
  - Dynamically generates the computation graph
  - Details for each construct in paper
  - Users can integrate custom parallel constructs
- Performance metrics are reproducible
  - Independent of physical machine used
  - Useful for debugging performance problems and comparing alternate implementations
- Computation graph can also be displayed visually

Abstract Execution Metrics

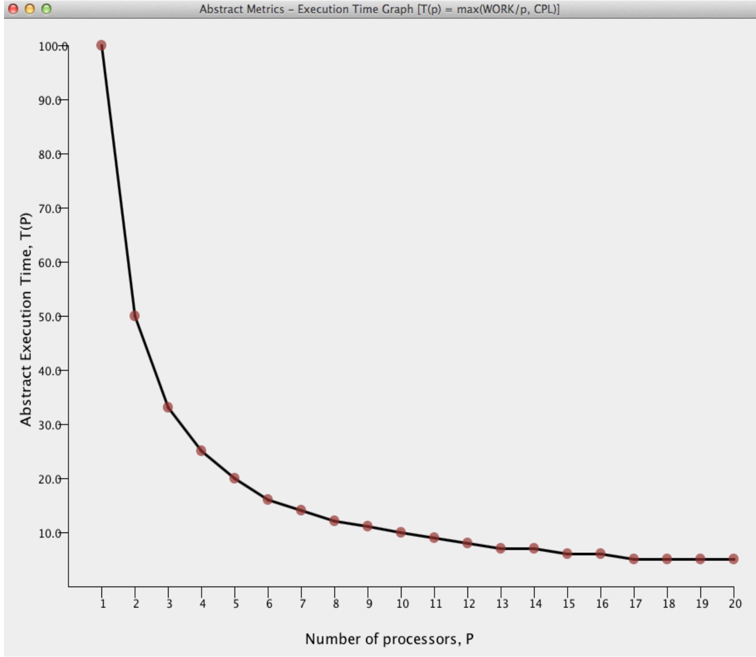
- Prints the total Work and Critical Path Length (CPL)
- Supported for all HJlib constructs
- Enabled using:

```
HjSystemProperty.abstractMetrics.set(true)
```

- Dump obtained by:

```
HjMetrics actualMetrics = abstractMetrics();
AbstractMetricsManager.
  dumpMetrics(actualMetrics);
```

- Can also use WORK and CPL metrics to obtain abstract time plots as shown on right

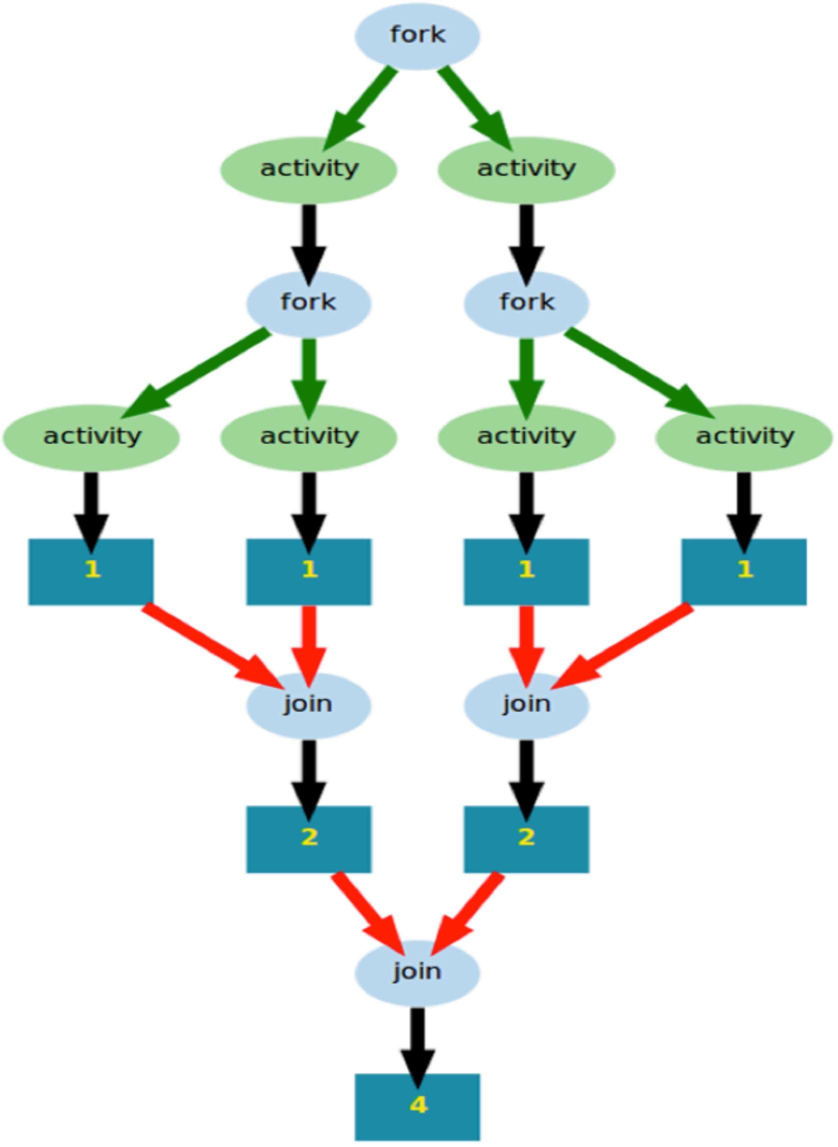


Visual Graphs

- Example: MergeSort
  - Use each comparison operation as work

```
final int mid = M + (N - M) / 2;
finish(() -> {
  async(() -> mergesort(A, M, mid));
  async(() -> mergesort(A, mid + 1, N));
});
merge(A, M, mid, N);
```

MergeSort Computation Graph

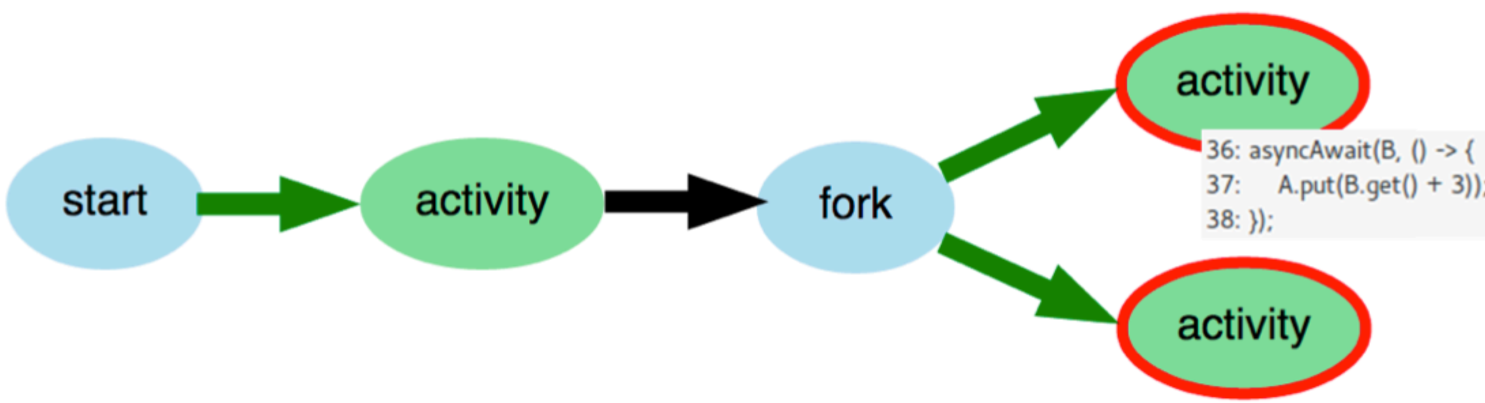


Deadlock detector

- Enable users to debug their programs while using the various synchronization constructs
  - Reports diagnostic error message
- If they venture beyond the deadlock-free subset of Hjlib
  - async/finish/future/phaser programs are deadlock-free
- DDFs/Actors/EventCounts/Other custom constructs can cause deadlocks
- Algorithm relies on tracking the number of
  - ready tasks in the work queue
  - blocked or pending tasks (suspended on EDCs)
  - Deadlock when work queue is empty but there are pending tasks

Deadlock Example

```
finish(() -> {
  HjDataDrivenFuture<Long> A = newDDF();
  HjDataDrivenFuture<Long> B = newDDF();
  asyncAwait(B, () -> A.put(B.get() + 3));
  asyncAwait(A, () -> B.put(A.get() + 5));
});
```



Pedagogic programming model

- Attractive tool for educators
- Educational resources available from COMP 322 website
  - Lecture notes and videos
- Extensive documentation and examples available
- Institutions can introduce parallel programming earlier in curricula
  - Based purely in Java
  - Garnered positive feedback from COMP 322 students
- Plan to use in MOOC version of COMP 322

https://wiki.rice.edu/confluence/display/PARPROG/COMP322

DEMO

- Setting up a simple HJlib project
- Some examples
  - ArraySum
  - QuickSort (Abstract Metrics)
  - Deadlock Detection
    - Data-Driven Futures
    - EventCount

Future work, Ongoing Research

- Performant Cooperative runtime
- Visual Computation Graphs for AEMs
- Visual display of Deadlocks
- Parallel constructs
  - Selectors – an extension to actors
  - Eureka-style computations
- Use of HJlib for multicore parallelism in Android applications
- . . .

- See http://habanero.rice.edu for related research & publications

Summary

- Pure library implementation on Java 8
- Introduces orthogonal parallel constructs with important safety properties
  - Simplifies parallel programming
- Feedback capabilities help the programmer debug applications
- Pedagogic: Attractive tool for both educators and researchers
- Educational material already available (COMP 322 lectures, videos, etc.)

Questions

- Pure library implementation on Java 8
- Introduces orthogonal parallel constructs with important safety properties
  - Simplifies parallel programming
- Feedback capabilities help the programmer debug applications
- Pedagogic: Attractive tool for both educators and researchers
- Educational material already available (COMP 322 lectures, videos, etc.)

```
import pppj.audience.Questions;
import pppj.audience.Comments;
import pppj.audience.Feedback;
```

Backup-Slides

Acknowledgments

- Rest of the Habanero Group
  - Vincent Cave
  - Jun Shirako
  - Sagnak Tasirlar
  - Jisheng Zhao

Habanero-Java library

- Inspired from pedagogic Habanero-Java (HJ) language
- Emphasis on the usability and safety of parallel constructs
- Used in second-year undergraduate course at Rice

COMP 322: Fundamentals of Parallel Programming (Spring 2014)

Instructor:	Prof. Vivek Sarkar, DH 3080	**Graduate TA:**	[redacted]
	Please send all emails to comp322-staff at rice dot edu	**Graduate TA:**	[redacted]
Assistant:	Penny Anderson, anderson@rice.edu, DH 3080	**Graduate TA:**	[redacted]

- Actively used in multiple research projects at Rice

Habanero-Java library

- Supports an explicit parallel programming model
  - A high level of abstraction
  - A wider range of parallel programming constructs
- A powerful and portable task parallel programming model
  - For the Java ecosystem
- Parallelize both regular and irregular applications

Example: EventCount

- Keeps a count of the number of events in a particular class
- advance: signal the occurrence of an event
- await(v): suspends task until the value of the eventcount is at least v
- read: return count of the advance operations so far

Example: EventCount

```java
public final class EventCount {

  Map<Long, EventDrivenControl> eventMap = new ConcurrentHashMap<>();
  AtomicLong eventCounter = new AtomicLong(0);

  public EventCount() {
    EventDrivenControl edc = newEDC();
    eventMap.put(0L, edc);
    edc.setValue(Boolean.TRUE);
  }
  public void advance() {
    long v = eventCounter.incrementAndGet();
    eventMap.putIfAbsent(v, newEDC());
    EventDrivenControl edc = eventMap.get(v);
    edc.setValue(Boolean.TRUE);
  }
  public void await(final long v) {
    eventMap.putIfAbsent(v, newEDC());
    EventDrivenControl edc = eventMap.get(v);
    suspend(edc);
  }
  public long read() {
    return eventCounter.get();
  }
}
```