Parallel Programming

Recitation Session 10

Thomas Weibel <weibelt@ethz.ch>

Laboratory for Software Technology,
Swiss Federal Institute of Technology Zürich

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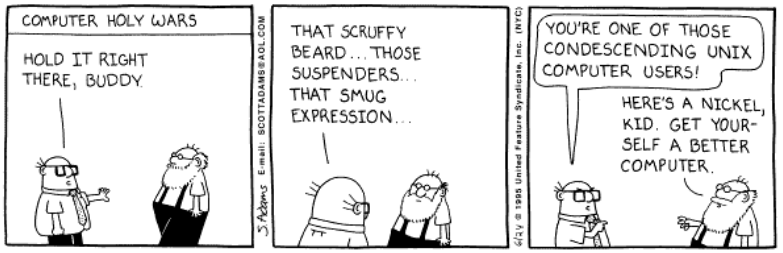
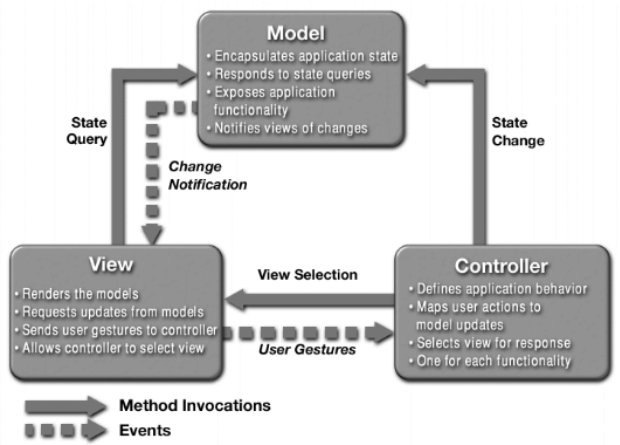
Executive Summary

- Model-View-Controller
- Solution to Game of Life
- OpenMP in a nutshell
- JOMP: OpenMP for Java



Outline

Model-View-Controller



Source: `http://java.sun.com/blueprints/patterns/MVC-detailed.html`

Roles of Participants

- Model:
  - domain specific knowledge
  - adds meaning to raw data
- View:
  - render data
  - capture user gestures
- Controller:
  - respond to events
  - asynchronously invoke changes on model

Outline

Design of the Solution

- `Application` class:
  - Main window and controls
  - Create and terminate the modeling thread
- `Field` class:
  - Drawing field: keeps copy of model state
- `Controller` class:
  - Has data and methods that can be applied on the data

Outline

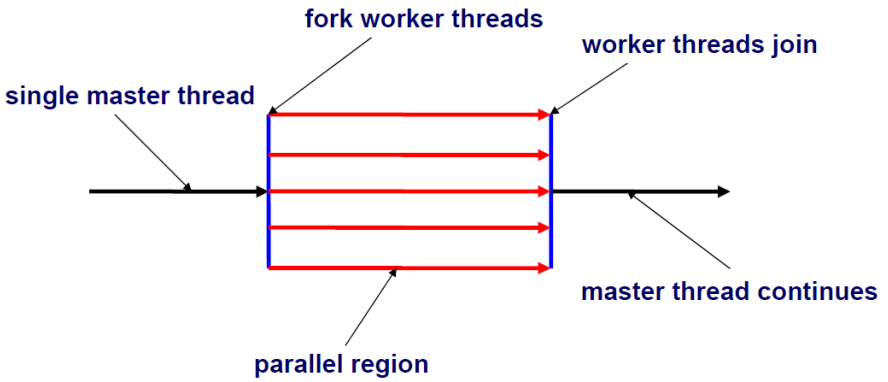
OpenMP in a Nutshell

- OpenMP is an API that consists of three parts
  - Directive-based language extension
  - Runtime library routines
  - Environment variables
- Three categories of language extensions
  - Control structures to express parallelism
  - Data environment constructs to express communication
  - Synchronization constructs for synchronization

Parallel Control Structures

Alter flow of control in a program

→ fork/join model



Parallel Control Structures

- Two kinds of parallel constructs
  - Create multiple threads (parallel directive)
  - Divide work between an existing set of threads
- Parallel directive
  - Start a parallel region
- For directive
  - Exploit data-level parallelism (parallelize loops)
- Sections directive
  - Exploit thread-level parallelism (parallelize tasks)
- Task directive (OpenMP 3.0)
  - Task with ordering (not possible with sections)

Communication & Data Environment

- Master thread (MT) exists the entire execution
- MT encounters a parallel construct
  - Create a set of worker threads
  - Stack is private to each thread
- Data Scoping
  - Shared variable: single storage location
  - Private variable: multiple storage locations (1 per thread)

Synchronization

- Co-ordination of execution of multiple threads
- Critical directive: implement mutual exclusion
  - Exclusive access for a single thread
- Barrier directive: event synchronization
  - Signal the occurrence of an event

Exploiting Loop-Level Parallelism

- Important: program correctness
- Data dependencies:
  - If two threads read from the same location and at least one thread writes to that location
    → Data dependence
  - Example:

```
for (i = 1; i < N; i++)
  a[i] = a[i] + a[i-1];
```

Loop carried dependence

Examples

```
for (i = 2; i <= n; i+= 2)
  a[i] = a[i] + a[i-1]
```

No dependence

```
for (i = 1; i <= n/2; i++)
  a[i] = a[i] + a[i + n/2]
```

No dependence

```
for (i = 1; i <= n/2 + 1; i++)
  a[i] = a[i] + a[i + n/2]
```

Dependence:

read(1+n/2)
write(n/2+1)

Parallel Directive

```
//omp parallel shared (a,b) private (c,d)
```

- Starts a parallel region
- `shared`: variable is shared across all threads
- `private`: each thread maintains a private copy

Distribute Loop Iterations

```
//omp for schedule(dynamic)

//omp for schedule(static)
```

- Distribute loop iterations to worker threads
- `dynamic`: loop-chunks are assigned to threads at runtime
- `static`: loop-chunk assignment before the loop is executed

Critical Section

```
//omp critical
```

- Starts a critical section
- Code section is executed by a single thread at a time

Outline

Tasks

Task 1

- Parallelize an existing implementation with OpenMP
- Which loop nest would you parallelize?
- Do you need a critical section?

Task 2

- Implement a Block Matrix Multiplication
- Divide the source matrices into sub-matrices
- Assign a thread to each sub-matrix

Which one performs better?

Outline

JOMP

- OpenMP is not natively supported by Java
- JOMP: source to source compiler
- See `http://www2.epcc.ed.ac.uk/computing/research_activities/jomp/index_1.html` for more information

How to use on the Console

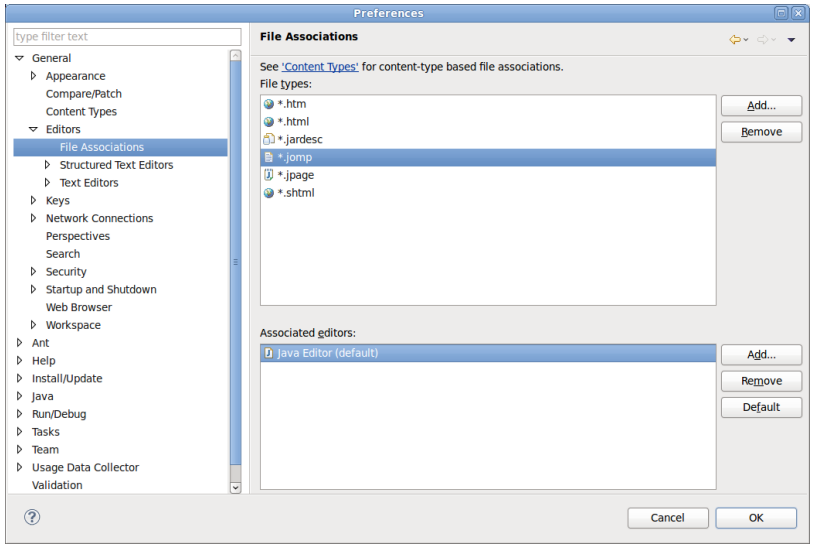
- Download `jomp1.0b.jar` from the course page
- Import external JAR file to your project (classpath)
  - `export CLASSPATH=$CLASSPATH:/path/to/jomp1.0b.jar`
  - Use option `-cp /path/to/jomp1.0b.jar` when calling Java to transform `file.jomp` into `file.java`
- Perform the following steps in the console
  - `java jomp.compiler.Jomp file.jomp`
    → generates `file.java`
  - `javac file.java`
  - `java file`

Hot to use in Eclipse

- Add `MatrixMultiply.jomp` to your project
- Add a new class `MatrixMultiply.java` to your project
  → this file will be overwritten by JOMP
- Copy `jomp1.0b.jar` to your project's `lib/` directory

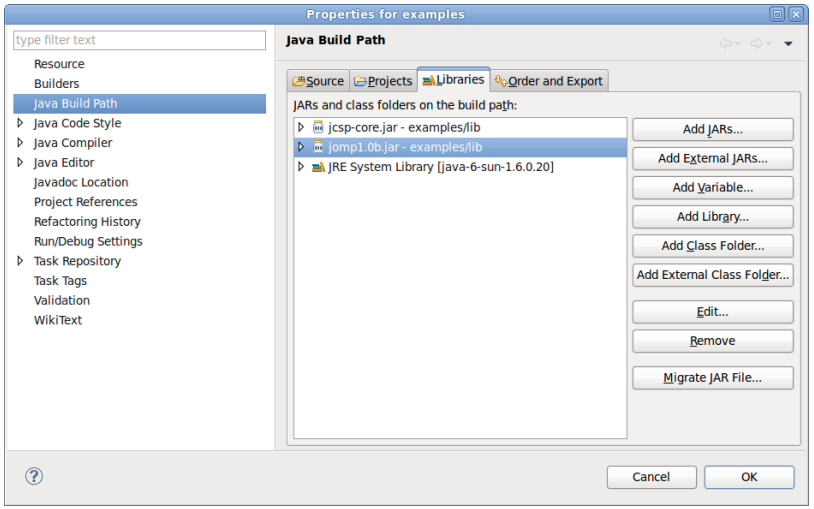
How to use in Eclipse: File Association

Add a file association for `*.jomp` as Java files (for syntax highlighting and auto completion):



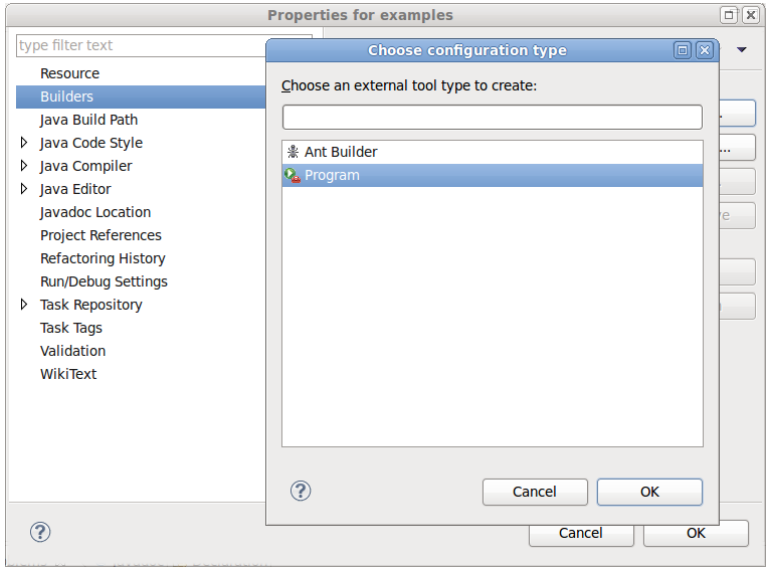
How to use in Eclipse: Java Build Path

Add `jomp1.0b.jar` to your project's build path:

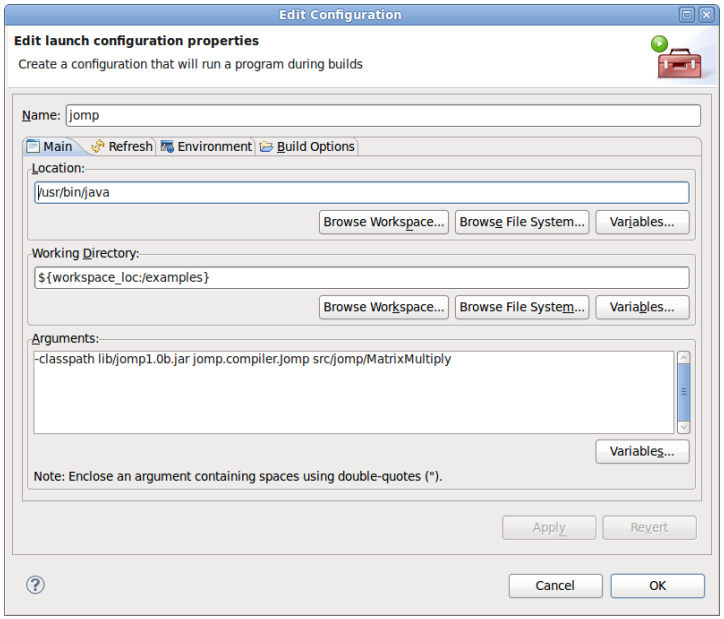


How to use in Eclipse: New Builder

Add a new builder for JOMP:

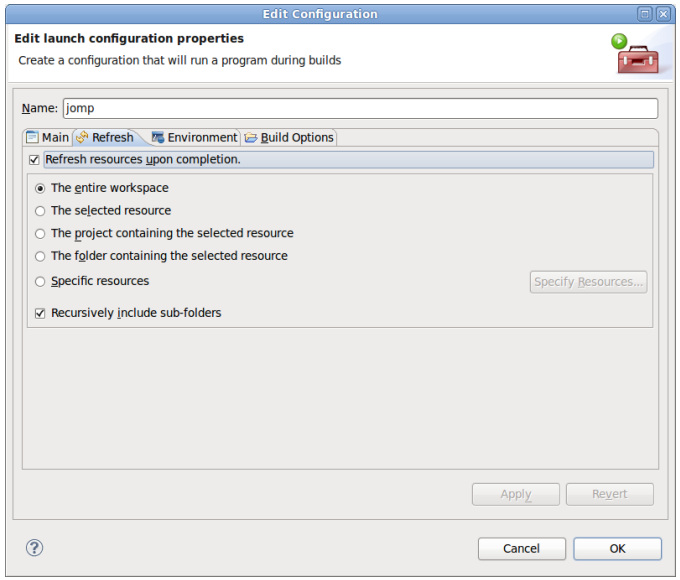


How to use in Eclipse: Configure Builder



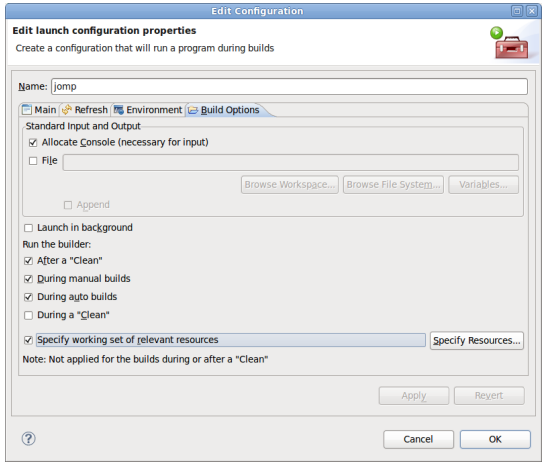
How to use in Eclipse: Configure Builder

Check “Refresh resources upon completion”:



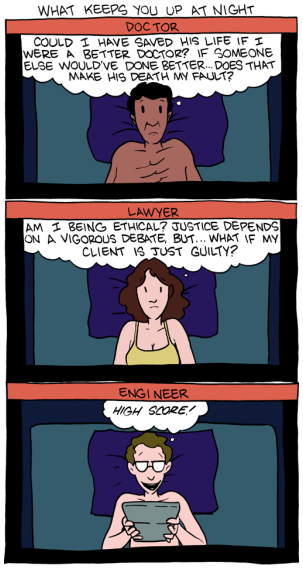
How to use in Eclipse: Configure Builder

- Check “During auto builds”
- Check “Specify working set of relevant resources”
- Click “Specify Resources” and select `MatrixMultiply.jomp`



Summary

- Model-View-Controller pattern and Game of Life
- OpenMP
- Data dependence
- How to use JOMP



Source: `http://www.smbc-comics.com/index.php?db=comics&id=1845`