Concurrent Programming with Revisions and Isolation Types

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Based on the article “Concurrent Programming with Revisions and Isolation Types”, OOPSLA ’10

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Outline

• Introduction
  • Main ideas
  • Assumptions of the presented programming model
• Revisions and Isolation Types
• Comparison to the classic locking schemes
• Case Study (SpaceWars3D game)
• Performance evaluation
• Implementation details
• Summary
Introduction

• Applications need to be responsive and benefit from exploiting parallel hardware.

• However, ensuring consistency of the data shared between concurrent tasks is often challenging.
Main ideas

• Reading and modifying data concurrently without complicated locking schemes that may introduce bugs.

• Instead of synchronizing access to the data, enable tasks to do real parallel modifications by creating isolated copy of the data (replication).

• Making concurrent programs as easy to code as their sequential versions.
Programming model

- Article describes programming model that simplifies sharing data between asynchronous tasks.

- **Declarative Data Sharing**
  - Programmer declares which variables are shared between tasks.
  - *Isolation Types*

- **Automatic Isolation**
  - Task operates on that data in isolation.

- **Deterministic conflict resolution**
  - After joining tasks *(revisions)* write-conflicts are solved deterministically.
  - Solving conflicts depends on declared *isolation types.*
Revisions

- Revisions represents the basic unit on concurrency.
- Each revision can fork and join other revisions.
- Applications starts in the main revision.

- **Two operations:**
  - fork – starts(forks) new revision
  - rjoin – joins two revisions (called joiner and joinee)

- Program execution can be easily presented on the revision diagrams.
Revisions (example)

```plaintext
versioned<int> x;
versioned<int> y;
x = 0
y = 0;
revision r = rfork {
    x = 1;
}

ty = x;
rjoin r;
print x, y;
```
Nested revisions

- Simplifies modular reasoning about program execution.

- Typically revisions fork its own inner revision and then join it.
  - Classic nesting of tasks.

- However, it is possible that inner (more nested) revision „survives” outer revision.
• Third situation is **impossible** because main revision doesn’t know handle to the inner revision. **It gets that handle after joining outer revision.**
Isolation types

- When joining revisions, we wish to **merge the copies of the shared data** back together.

- Merging process is defined by **isolation types**.

- Programmer must choose **the right isolation type** for every single shared object.

- Isolation types fall into two categories:
  - **versioned** <T>
  - **cumulative** <T, f>
versioned <T>

- Changes the current value to the revision that is performing a join to the current value of the revision that is being joined.
- If there were no modifications in the joinee revision then do nothing.
- It is a good choice for tasks that have relative priorities.
versioned <T>

```cpp
versioned<int> x;
versioned<int> y;

typedef struct { int x,y } coord;
versioned<coord> pos;
```

```
x=0
y=0

y=1
x=1

assert(x==1)
assert(y==1)

pos.x=0
pos.y=0

pos.y = 1
pos.x = 1

assert(pos.x ==1)
assert(pos.y ==0)
```
cumulative \langle T, f \rangle

- Effect of the merge is determined by a general merge function.

- **Merge function** takes three arguments:
  - original value
  - current value of the joiner revision
  - current value of the joinee revision
int merge(int original, int master, int revised)
{
    return master + revised - original;
}
Comparison with locking scheme

• **Traditional locking scheme**
  • Requires programmers to think about placement of critical sections
  • Complicates code readability and maintenance
  • Reduces concurrency by pausing tasks
    • Eg. animating and rendering game objects in separate tasks

• **Presented solution**
  • Isolation of the read-only tasks and single writer task
    • so-called *double-buffering*
  • Might be not the most space-efficient solution
Comparison with transactions

```c
void foo()
{
    if (y == 0)
        x = 1;
}

void bar()
{
    if (x == 0)
        y = 1;
}
```

**Revisions and Isolation Types:**

```c
versioned<int> x,y;
x = 0; y = 0;
revision r = rfork { foo(); } bar();
rjoin r;
assert(x = 1 ∧ y = 1);
```

**Transactions:**

```c
int x,y;
x = 0; y = 0;
task t = fork { atomic { foo(); } } atomic { bar(); }
join t;
assert((x = 1 ∧ y = 0) ∨ (x = 0 ∧ y = 1));
```
Case Study

SpaceWars3D
Game designed to teach DirectX programming in C#
12 000 lines
Parallelizing the game loop

```c
while (!done)
{
    input.GetInput();
    input.ProcessInput();
    physics.UpdateWorld();
    for (int i = 0; i < physics.numsplits; i++)
        physics.CollisionCheck(i);
    network.SendNetworkUpdates();
    network.HandleQueuePackets();
    if (frame % 100 == 0)
        SaveGame();
    ProcessGuiEvents();
    screen.RenderFrameToScreen();
    audio.PlaySounds();
    frame++;
}
```

- **RenderFrameToScreen()**
  It can execute in parallel with other tasks.
  Reads objects position.

- **UpdateWorld()**
  Reads and modify objects position.

- **CollisionCheck(i)**
  It can be parallelized.
  Reads and modify objects position.

- **Objects position is also read by**
  SendNetworkUpdates()
  HandleQueuePackets()
Parallelizing the game loop (2)

Revision UpWrl, SendNtw, HdlPckts, AutoSave;
Revision[] ColDet = new Revision[physics.numsplits];

while (!done)
{
    input.GetInput();
    UpWrl = rfork {
        input.ProcessInput(); physics.UpdateWorld();
    }
    for (int i = 0; i < physics.numsplits; i++)
    {
        ColDet[i] = rfork { physics.CollisionCheck(i); }
    }
    SendNtw = rfork { network.SendNetworkUpdates(); }
    HdlPckts = rfork { network.HandleQueuedPackets(); }
    if (frame % 100 == 0 ∧ AutoSave == null)
    {
        AutoSave = rfork { SaveGame(); }
    }
    ProcessGuiEvents();
    screen.RenderFrameToScreen();
    join(UpWrl);
    for (int i = 0; i < physics.numsplits; i++)
    {
        join(ColDet[i]);
    }
    join(SendNtw);
    join(HdlPckts);
    if (AutoSave != null ∧ AutoSave.HasFinished()) {
        join(AutoSave);
        AutoSave = null;
    }
    ...
}
Parallelizing the game loop (3)

- **Declared isolation types:**
  - `VersionedValue<T>` - mainly simple types
  - `VersionedObject<T>` - asteroids, positions, particle effects
  - `CumulativeValue<T>` - message buffer
  - `CumulativeList<T>` - lists of asteroids

- **CollisionsCheck** could be executed in parallel. Optimizing

- **RenderFrameToScreen** cannot be parallelized, but it can be executed in parallel with other tasks

- Updates from the network have higher priority than updates done by **UpdateWorld** or **CollisionsCheck**

- **Deterministic Record and Replay**
  - Used in performance evaluation
Evaluation

Testing environment:
Intel Xeon W3520 (quad-core) 2.66Ghz, 6GB of DDR3,
NVIDIA Quadro FX580 512MB, Windows 7 Enterprise 64-bit
Revisions overhead

- Revision overhead causes slowdown of 5%
  - Execution in single thread
  - Collision detection task takes about $82\%$ of the frame time.
Revisions overhead (2)

![Graph showing average frame time breakdown (ms) for Sequential and Revisions (seq). The breakdown is divided into categories: Join, Others, ColDet, UpWrl, and Renderer. The numbers for Sequential and Revisions (seq) are compared in a table below the graph.]

<table>
<thead>
<tr>
<th></th>
<th>Sequential</th>
<th>Revisions (seq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Join</td>
<td>0</td>
<td>0.239477711</td>
</tr>
<tr>
<td>Others</td>
<td>0.023597575</td>
<td>0.030098449</td>
</tr>
<tr>
<td>ColDet</td>
<td>15.48415</td>
<td>15.76237</td>
</tr>
<tr>
<td>UpWrl</td>
<td>0.2467515</td>
<td>0.4880668</td>
</tr>
<tr>
<td>Renderer</td>
<td>3.022258</td>
<td>3.214011</td>
</tr>
</tbody>
</table>
Memory consumption

- If revision writes to a versioned object then revisioning subsystem needs to clone object to enforce isolation.

<table>
<thead>
<tr>
<th># asteroids</th>
<th>Sequential</th>
<th>Revisions</th>
<th>Overhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>1,162,588</td>
<td>1,578,660</td>
<td>1.36</td>
</tr>
<tr>
<td>900</td>
<td>1,199,388</td>
<td>1,654,100</td>
<td>1.38</td>
</tr>
<tr>
<td>1000</td>
<td>1,236,196</td>
<td>1,734,200</td>
<td>1.40</td>
</tr>
<tr>
<td>1100</td>
<td>1,277,092</td>
<td>1,814,296</td>
<td>1.42</td>
</tr>
<tr>
<td>1200</td>
<td>1,324,932</td>
<td>1,914,504</td>
<td>1.44</td>
</tr>
<tr>
<td>1300</td>
<td>1,361,732</td>
<td>1,991,304</td>
<td>1.46</td>
</tr>
<tr>
<td>1400</td>
<td>1,398,532</td>
<td>2,068,104</td>
<td>1.48</td>
</tr>
<tr>
<td>1500</td>
<td>1,435,332</td>
<td>2,144,904</td>
<td>1.49</td>
</tr>
</tbody>
</table>
Parallel performance

- Average speedup of **2.6x** on quad-core processor
- Up to **3.03x** speedup for 1500 asteroids
- Render task takes **95.5%** of the frame time (*collisions check speedup*)

![Graph showing performance comparison between sequential and revisions methods.](image-url)
Implementation

- **C# library**

- **Revisions**
  - Stores current segment that points to the segment created for that revision after last fork
  - Root segment is the segment right above fork

- **Segments**
  - Tree structure
  - Stores versioned data
  - Ancestors of the current segment can be removed after join if there is no other revisions that uses them.

```csharp
class Revision {
    Segment root;
    Segment current;
    ...
}

class Segment {
    int version;
    int refcount;
    Segment parent;
    List<Versioned> written;
    ...
}

class Versioned<T> : Versioned {
    Map<int, T> versions;
    ...
}
```
Revisions and segments (example)
Forks and joins

- **Fork**
  - Creates new current segments for both revisions
  - Assigns new revision with the new thread

- **Join**
  - Creates one new segment
  - Merges versioned objects from both revisions
  - Releases unused ancestors of the current segment of the joined revision
Summary

• Programming model based on revisions and isolation types.

• Efficient mechanism for executing different tasks within interactive applications.

• Future work:
  • Optimizations
  • Executing tasks on GPU
  • Applications that run on multi-core processors without full shared-memory guarantees
  • Application that run in the cloud
Thank you.
Questions?