Transactional Memory

Concurrency unlocked Programming

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Background

- Around 2004, 50 years of exponential improvement in the performance of sequential computers end, due to **power and cooling concerns**
- In the terminology of Intel's founder, Andrew Grove, this is an inflection point—a "**time in the life of a business when its fundamentals are about to change**"
- **Multiprocessor**

Motivation

- Difficulty of Multiprocessor Programming: **Parallelism** and **Nondeterminacy**
  - **Prune nondeterminism**
  - **Violation(atomicity-violation, order-violation)**
  - **Deadlock**
- Parallelism programming (Multi-thread programming) lacks comparable **abstraction mechanisms**.

Database Transaction

- A **transaction** specifies a program semantics in which a computation **executes as if it was the only computation accessing the database**. Other computations may execute simultaneously, but the model **restricts the allowable interactions among the transactions**.
- Offer an **abstraction mechanism** in database systems for reusable parallel computations.
- **ACID** (Atomic, Consistent, Isolated and Durable)

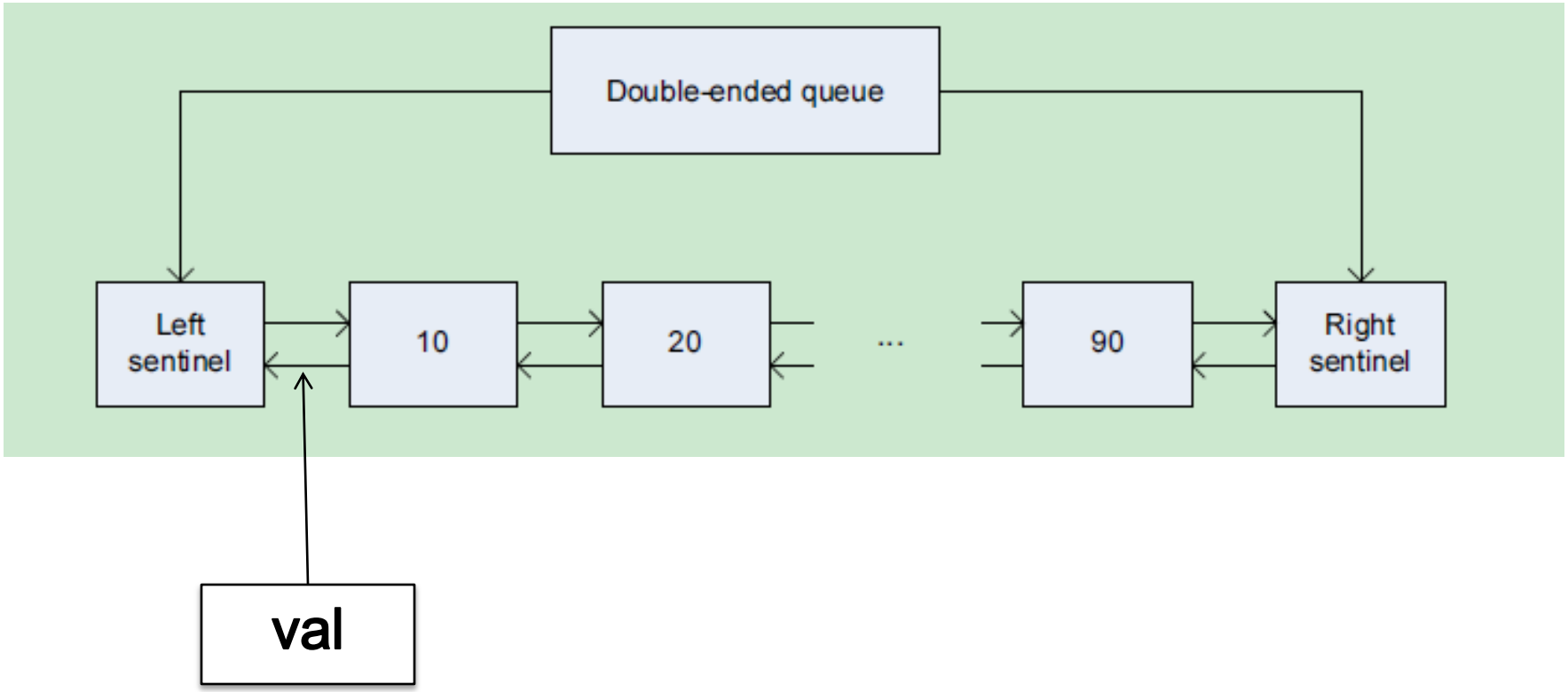
Transactional Memory History

- In 1977, Lomet proposed the idea to **map database transaction into programming language**, but no implementation
- In 1993, Herlihy and Moss proposed **hardware supported transactional memory**
- In 1993, Stone et al. proposed an atomic multi-word operation known as **"Oklahoma Update"**
- In recent years, a huge ground swell of interest in both hardware and software systems for implementing transactional memory.

Transactional Memory

- **"Steal" ideas from database transaction**. (A transaction is a sequence of actions that appears **indivisible** and **instantaneous** to an outside observer.)
- The properties of transactions provide a convenient abstraction for **coordinating concurrent reads and writes of shared data** in a concurrent or parallel system.

Example


Double-ended queue
Left sentinel
10
20
...
90
Right sentinel
val

Example

```
void PushLeft(DQueue *q, int val) {
  QNode *qn = malloc(sizeof(QNode));
  qn->val = val;
  do {
    StartTx();
    QNode *leftSentinel = ReadTx(&(q->left));
    QNode *oldLeftNode = ReadTx(&(leftSentinel->right));
    WriteTx(&(qn->left), leftSentinel);
    WriteTx(&(qn->right), oldLeftNode);
    WriteTx(&(leftSentinel->right), qn);
    WriteTx(&(oldLeftNode->left), qn);
  } while (!CommitTx());
}
```

Mechanisms of Transactional Memory

- Manage the **tentative work** that a transaction does while it executes, akin the `left` and `right` fields of the `qn` object.
- Ensure **isolation** between transactions, **detect and resolve conflicts**
  - **"Eager conflict detection": identifies conflicts when running.**
  - **"Lazy conflict detection": detect only when they try to commit.**

Integrated with high-level programming language

```
void PushLeft(DQueue *q, int val) {
  QNode *qn = malloc(sizeof(QNode));
  qn->val = val;
  atomic {
    QNode *leftSentinel = q->left;
    QNode *oldLeftNode = leftSentinel->right;
    qn->left = leftSentinel;
    qn->right = oldLeftNode;
    leftSentinel->right = qn;
    oldLeftNode->left = qn;
  }
}
```

Software Transactional Memory

- A rich vein of research over the last decade, focusing on approaches that can be implemented on current mainstream processors.
- There is a very large space of different possible STM designs, and simple **version-number-based approach** is by no means the state of the art.

Software Transactional Memory

Record Version number into **read-log**

Record the change into **write-log** and **undo-log**

```
void PushLeft(DQueue *q, int val) {
  QN                                    ode));
  qr
  do
    StartTx();
    QNode *leftSentinel = ReadTx(&(q->left));
    QNode *oldLeftNode = ReadTx(&(leftSentinel->right));
    WriteTx(&(qn->left), leftSentinel);
    WriteTx(&(qn->right), oldLeftNode);
    WriteTx(&(leftSentinel->right), qn);
    WriteTx(&(oldLeftNode->left), qn);
  } while (!CommitTx());
}
```

Check conflicts based on version number and decide commit or abort. If commit, increase the version number.

Hardware Transactional Memory

- Provide advantages over STM
  - **Lower overheads**
  - **Better power and energy profiles**
  - **Less invasive**
  - **Strong isolation**
- Identifying Transactional Locations: Via extensions to instruction set
  - **Explicitly transactional HTMs: more flexible**
  - **Implicitly transactional HTMs: reuse**
- Tracking Read-Sets and Managing Write-Sets
  - **Extend the mechanisms of current caches and buffers to track read-sets and manage write-sets**

Hardware Transactional Memory

- Detecting Data Conflicts: Cache coherence protocol
  - **Cache state: MESI (modified/exclusive/shared/invalid)**
- Resolving Data Conflicts
  - **Eager conflict detection: aborting the transaction on the processor that receives the conflicting request, and transferring control to software following such an abort.**
- Managing Architectural Register State
  - **Create a shadow copy of architectural registers at the start of a transaction for restoration.**

Hardware Transactional Memory

- Committing and Aborting HTM Transactions: making all transactional updates visible to other processors instantaneously
  - **Obtain the write permissions for all the transactional addresses**
  - **Block any subsequent requests from other processors**
  - **Drain the store buffer into the data cache**

Application

- Manage **shared-memory data structures** in which scalability is difficult to achieve via lock-based synchronization
- Some Examples
  - **Double-ended queue operations (**`PushLeft`**)**
  - **Graph algorithms**
  - **Quake game server**
- Limitations
  - **The performance of code executing within a transaction can be markedly slower than the performance of normal code**
  - **Parallel/Semantic errors**

Overall Conclusion

- Transactional Memory model provides an unlocked solution and an abstraction mechanism to parallel programming.
- Software Transactional Memory: coexist with other programming abstractions and depends on the environment.
- Hardware Transactional Memory: Efficient but application sensitive.
- Transactional Memory is not a panacea.

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