Indirect Communication

To do ...

- Today
- Space and time (un)coupling
- Common techniques

How standards proliferate:

SITUATION: THERE ARE 14 COMPETING STANDARDS.

14?! RIDICULOUS! WE NEED TO DEVELOP ONE UNIVERSE STANDARD THAT COVERS EVERYONE'S USE CASES. YEAH!

SITUATION: THERE ARE 15 COMPETING STANDARDS.
Direct coupling communication

- With R-R, RPC, RMI
  - Space coupled – Sender knows the identity of the receiver and vice-versa
    - If server fails, hard to replace; clients must explicitly deal with that
  - Time coupled – Server and receiver must both exist at the time of communication
    - If the server is being restarted while a client sends a message …

<table>
<thead>
<tr>
<th>Space coupling</th>
<th>Time-coupled</th>
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<td>Communication directed to a given receiver(s) that must be available at the time</td>
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Indirect communication

- Through an intermediary, with no direct coupling between senders/receivers
- Different types, with differences in nature of the intermediary
- … and type of coupling

Forms of (un)coupling

- Space – (No) need to know the identity of the other
- Time – (No) need to exist at the same time
Space and time (un)coupling

- **Space uncoupling**
  - No need to know the identity of the other party
  - Can change, update, replicate, move senders/receivers
  - E.g., IP multicast

- **Time uncoupling**
  - No need to exist at the same time
  - It’s ok if either party gets disconnected for a bit
  - E.g., Mailbox
  - Not the same as asynchronous – *Why not?*
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<td>Space uncoupling</td>
<td>Sender does not need to know ID of receiver but they must exist at the same time</td>
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<td><em>e.g. IP multicast</em></td>
<td><em>e.g. Message oriented</em></td>
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Examples of indirect communication

- Group communication
  - An abstraction over multicast communication
  - Space uncoupled

- Publish-subscribe systems
  - The most widely used indirect comm. techniques
  - Space uncoupled and possible time uncoupled

- Message queues
  - Space and time uncoupling through a msg queue

- Shared memory
  - Distributed shard memory and tuple spaces
Group communication

- Sender communicates with a group, as a whole
  - Without knowing the identity of members
  - An abstraction over multicast (IP or overlay)
- Typically to process groups
  - Processes can join/leave
  - A message to the group reaches all (broadcast)
- Some common uses
  - Reliable dissemination (e.g., financial reports)
  - Collaborative applications (e.g., multiuser games)
  - Highly-available services
  - System monitoring and management
Group communication

- Not just programmer’s convenience

More efficient use of bandwidth – just once per network link
Groups and group management

- Process and object groups
  - Messages, typically unstructured byte arrays, are delivered to processes ~ socket
  - A collection of objects that process the same set of invocations concurrently; client invokes a method once on a local proxy

- Groups may be
  - Closed or open – only members or anyone can send to group
  - Overlapping or not – processes can be members of 1+ group
  - Synchronous or asynchronous

- Group membership
  - Membership service provides interface for membership changes, failure detection and notification
Reliable and ordered multicast

- **Reliable**
  - From one-to-one communication
    - Integrity – msg received is the one sent and no msg is delivered twice
    - Validity – any outgoing msg is eventually delivered
  - Agreement – if msg is delivered to one, it is delivered to all

- **Ordered**
  - FIFO ordering – source ordering, preserve order of the sender
  - Causal – causally related msgs arrive in the same order everywhere; if a msg *happens before* another msg this so called *causal relationship* is preserved in the delivery
  - Total ordering – All msgs arrive in the same order everywhere
An example based on Birman and van Renesse’ work on ISIS, Horus and Ensemble

Includes channels (handle onto a group), building blocks and a composable stack

- Every module can be stacked over/bellow any other
- Not all stacks make sense, of course
- CAUSAL – causal ordering
- FRAG – configurable packetization
- GMS – group membership system to maintain consistent view of the group
- MERGE – Network partitions and group merges
- ...

JGroups toolkit as an example
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Publish-subscribe

- AKA distributed event-based systems
  - One of the most widely used indirect communication model
  - E.g., CORBA Events, Scribe, Echo, Google Cloud Pub/Sub, …

- Publishers and subscribers
  - Publishers publish events, subscribers subscribe to them

- The pub/sub system job
  - Match subscriptions with published events, ensure delivery

- Example applications
  - financial systems, live feeds, ads, search, monitoring apps, …
Programming and subscription models

- **Simple programming model**
  - Publishers *publish(e)*, subscribes *subscribe(f)* where *f* is a filter on the type of events they care for, *unsubscribe()*

- **Different subscription models**
  - **Channel-based**
    - Basic, publishing to named channels
  - **Topic or subject based**
    - Notifications are expressed in terms of a number of fields; one field may denote the topic
  - **Content-based**
    - Allows subscription over a range of fields
  - **Other types explored**
    - Type-, context- and concept-based and more complex event processing
Goal – efficient delivery of the right events to the right subscribers with appropriate security considerations

Some design options

- Centralized/distributed
  - Centralized event broker
  - Network of brokers

- Full P2P – not distinction between publishers and subscribers, i.e., everyone is a broker

- Routing options …
**Routing options**
- Flooding – send to all, matching done at the subscriber
- Filtering – every node in the network of brokers does filtering-based routing
- Rendezvous – a node responsible for matching notifications and subscribers
Back in 5’

- … message queues and shared memory
(Distributed) message queues

- Point-to-point comm. through an intermediary queue
  - Senders place msgs into a queue, receivers removed them
    - Queues correspond to buffers at communication servers
  - E.g., IBM WebSphere MQ, Java Messaging Service, Oracle’s Stream Advanced Queuing
(Distributed) message queues

- Details on messages
  - Typically include dest queue, priority, delivery mode, and body
    - In Oracle’s AQ, messages are rows in a DB table/queue
  - Messages are persistent
  - Typical queuing policies FIFO and priority-based

- Use for app integration – broker takes care of application heterogeneity
  - Transforms incoming messages to target format
  - Often acts as an application gateway
  - May provide subject-based routing capabilities
(Distributed) message queues

- Styles of receive
  - Blocking – Block until an appropriate message is available
  - Non-blocking – Polling to see if a message is available
  - Notify – Notify when a message arrives

- Centralized and distributed message queues
  - In WebSphere MQ, queues are managed by *queue managers*
  - Queue managers can be inter-connected as brokers in pub-sub
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Shared memory approaches

- Distributed share memory
  - Allow networked computers to share memory
  - How to make distributed memory appear local?
  - Leverage MMU
    - Page fault handler invokes DSM protocol
    - Bring page from a remote node instead of from HD
  - Of course, underneath it all – message passing

- Compare with message passing
  - No need to marshalled/unmarshalled data, send/receive, …
  - Synchronization via typical shared-memory programming constructs like locks
  - Potentially easier to program for with a performance cost
Shared memory approaches

- **Simplest design**
  - Each virtual page in one machine at a time
    - no caching
  - A directory keeps track of things
    - potentially a bottleneck
  - Distributed directory – hash(page#)
- Design issues
  - Size of the page
  - Caching and consistency models
Shared memory and consistency

- **Consistency model**
  - *When changes to data are seen at a given processor*
  - Defines the programmer’s view, placing restrictions on what values can be returned by a read (a contract)
  - Determines what optimizations are possible

- **E.g., sequential consistency**
  - Some basic notation
    - $W_i(x)a$ – process $P_i$ wrote value $a$ to $x$
    - $R_i(x)b$ – process $P_i$ read value $b$ from $x$

\[
\begin{array}{c}
P1: W(x)a \\
\hline
P2: \ \ \ \ R(x)\text{NIL} \ \ \ R(x)a \\
\hline
\end{array}
\]

- Time to propagate
Sequential consistency

- **Result of execution – as if**
  - *operations of all processes were executed in some sequential order, and …*
  - *the operations of each process appear in this sequence in the order specified by its program*
  - i.e., Any valid interleaving of operations is OK, but all processes see the same interleaving

- **Linearizable – interleaving is consistent with real time at which operations occurred in the actual execution**

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<tr>
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<th>P2: W(x)b</th>
<th>P3: R(x)b R(x)a</th>
<th>P4: R(x)b R(x)a</th>
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<td></td>
<td></td>
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<td>Absolute time does not matter</td>
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The burden of sequential consistency

- Processor must ensure that previous memory operation is complete before proceeding to the next.

So …
  - Determine completion of write; get ack for all.
  - If caching, write invalidates or updates all cached copies.
  - Hold off on read requests until all writes are complete.

Maybe we can relax this a bit if next steps don’t depend on the value.
  - Causal consistency …
Shared memory – tuple spaces

- First introduced with *Linda* by D. Gelernter
  - Adopted by IBM Tspaces, JavaSpaces, …

- Programming model
  - Processes communicate through a tuple space, a shared collection of tuples
  - Tuple – a sequence of 1+ typed data fields
  - Operations
    - Write – adds a tuple
    - Read – returns the value of a tuple w/o changing the tuple space
    - Take – returns the value of a tuple and removes the tuple
    - For read/take, give a template; system returns a tuple that matches
  - Tuples are immutable - to change one, take it and write as new
Shared memory – tuple spaces

- Original Linda model had a single, global tuple space
  - Not optimal for a large system, e.g., aliasing of tuples
  - Aliasing – read/take matching tuples by accident
  - Following systems use multiple tuple spaces and some allow the dynamic creation of tuple spaces

- Linda was anticipated as a centralized system
  - Performance and reliability concerns
  - Following systems support distributed tuple spaces
  - Different approaches from state machine replication and tuple-specific approaches to simple partitioning of the tuple space
The power of indirection in communication – communication through an intermediary
– Uncoupling in space and/or time

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<th>Pub/sub</th>
<th>MQ</th>
<th>DSM</th>
<th>Tuples</th>
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<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time uncoupled</td>
<td>Possible</td>
<td>Possible</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Style</td>
<td>Comm</td>
<td>Comm</td>
<td>Comm</td>
<td>State</td>
<td>State</td>
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<tr>
<td>Comm pattern</td>
<td>1-m</td>
<td>1-m</td>
<td>1-1</td>
<td>1-m</td>
<td>1-1/1-m</td>
</tr>
<tr>
<td>Scalability</td>
<td>Limited</td>
<td>Possible</td>
<td>Possible</td>
<td>Limited</td>
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</tr>
<tr>
<td>Associative</td>
<td>No</td>
<td>Content-based only</td>
<td>No</td>
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