Message reliability and caching for publish/subscribe systems

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Publish/subscribe

Message completeness

Temporal logic

Safety and Liveness

Axioms for p/s systems

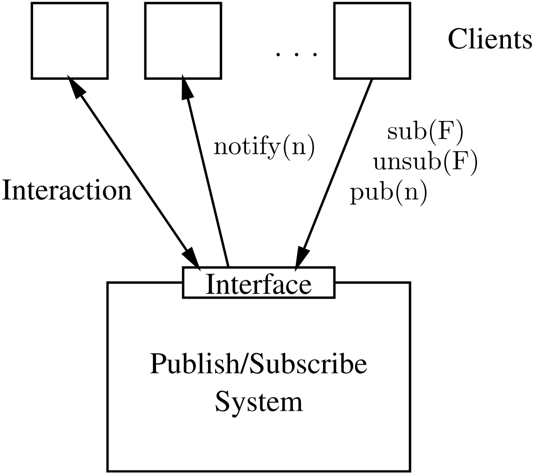
Distributed Implementaion

Rebeca

Publish/Subscribe

- Enables loosely coupled communication using notifications.
- Two kinds of "clients"
  - Producers publish notifications
  - Consumers subscribe to notifications
- Notification service
  - Decouples producers from consumers
  - Delivers a published notification to all consumers with a matching subscription

Interface



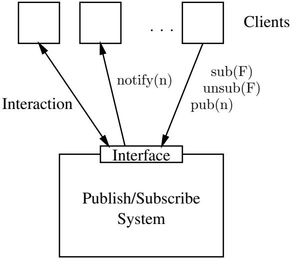
Clients
. . .
notify(n)
sub(F)
unsub(F)
pub(n)
Interaction
Interface
Publish/Subscribe
System

Basic Definitions and Assumptions

- A filter F is a mapping from the set of notifications $\mathcal{N}$ to the boolean values *true* and *false*.
- A notification n matches a filter F iff $F(n) = \textit{true}$.
- Set of notifications matched by a filter F and by a set of filters $\mathcal{A}$ is denoted by $N(F)$ and $N(\mathcal{A})$, respectively.
- Notifications are unique and can be published only once.

Black box view of a publish/subscribe system

- Describes the system behavior by solely looking at its interface.



- Interface Operations (set of all actions A)

$sub(Y, F)$	Client Y subscribes to filter F
$unsub(Y, F)$	Client Y unsubscribes to filter F
$ack(Y, F)$	System notifies client Y about message completeness guarantee
$notify(Y, n)$	System notifies client Y notified about n
$pub(X, n)$	Client X publishes n

Multicast

- publish/subscribe is special type of multicast
  - event-based
  - dynamically created groups
- problems classically considered for multicast:
  - message completeness
  - message order
  - etc.

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- in an asynchronous system, this is not achievable if messages are not cached (subscription must first be propagated through the network)
- *better:* after a client subscribes to a filter, there is a future time at which he is guaranteed to see all messages published thereafter
- *even better:* after a client subscribes to a filter, there is a future time *the client is notified about* at which he gets message completeness guarantee

The Need for a formal treatment

- A formal specification
  - defines precisely what is expected from a correct system and
  - allows to reason about the correctness of an implementation.
- A formal treatment gives new insights that could otherwise be overlooked!
- *Linear Temporal Logic* offers a formalizm suitable for characterization of the behaviour of distributed systems

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$$\sigma = s_0, op_1, op_2, \ldots, op_n \tag{1}$$

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- predicate applied to trace σ refers to *first state* s_0 or *first operation* op_1

Temporal quantifiers

For some formula ϕ and $\sigma = s_0, op_1, op_2, \ldots, op_n$,

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- $\bigcirc\phi(\sigma)$ holds iff ϕ holds for the trace $s_1^\sigma, op_2, \ldots$.

LTL and Concurrency

- LTL is well-suited to describe concurrent systems
- A concurrent system is replaced by a nondeterministic sequential one.
- The concurrent execution of two operations in the real system is replaced in the model by the nondeterminism of which one occurs first.
- This type of nondeterminism is conceptually different from that studied in the area of automata theory ($\Rightarrow$ branching time).

LTL Examples

- $\Diamond\Box A$
- $\Box\Diamond A$
- $A \Rightarrow \Diamond B$
- $\Box[A \Rightarrow \Diamond B]$
- $\Box[A \Rightarrow \Box A]$
- $\Box[\Box A \Rightarrow \Diamond\Box B]$
- $\Box[A \vee \Box\neg A]$

State Variables in p/s systems

P_X	set of *published notifications*
S_Y^{ack}	set of *acknowledged subscriptions*
S_Y^{pend}	set of *pending subscriptions*
D_Y	multiset of *delivered notifications*

Initial values of state variables: $\emptyset$ for all of them

Effect of interface operations on state variables

$pub(X, n)$	$P'_X = P_X \cup \{n\}$
$sub(Y, F)$	$S_Y^{\mathrm{pend}'} = S_Y^{\mathrm{pend}} \cup \{F\}$
$unsub(Y, F)$	$S_Y^{\mathrm{ack}'} = S_Y^{\mathrm{ack}} \setminus \{F\}$; $S_Y^{\mathrm{pend}'} = S_Y^{\mathrm{pend}} \setminus \{F\}$
$ack(Y.F)$	$S_Y^{\mathrm{pend}'} = S_Y^{\mathrm{pend}'} \setminus \{F\}$; $S_Y^{\mathrm{ack}'} = S_Y^{\mathrm{ack}} \cup \{F\}$
$notify(Y, n)$	$D'_Y = D_Y \cup \{n\}$

Safety and Liveness

- Safety Conditions
  - Something "irremediably" bad will never happen.
  - Usually, phrased as an invariant of the system.
  - Usually, trivially satisfied by doing *nothing*.
  - General form: $\mathit{Init} \Rightarrow \Box\neg A$.
  - Violation can be detected after *finite* time.
  - E.g. partial correctness (Program never halts with wrong result)

Safety and Liveness (2)

- Liveness Conditions
  - Something “good” that should happen eventually happens.
  - Usually, trivially satisfied by doing *everything*.
  - General form: $\mathit{Init} \Rightarrow \Box[A \Rightarrow \Diamond B]$.
  - Violation can be detected after *infinite* time only.
  - Example: Termination (Program eventually halts)
- Many useful system properties (e.g., total correctness) can be expressed as the intersection of safety and liveness conditions.

Safaty axioms

A *publish/subscribe system* satisfies *message complete safety* if

- $$\Box\Big[\mathit{notify}(Y, n, X) \Rightarrow [\bigcirc\Box\neg\mathit{notify}(Y, n, X)]\Big] \qquad (2)$$

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- $$\Box\Big[notify(Y, n, X) \Rightarrow \exists F \in S_Y^{pend} \cup S_Y^{ack}.\ n \in N(F)\Big] \tag{4}$$

Liveness axioms

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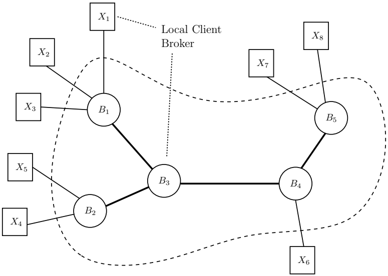
- $$\Box\Big[(sub(Y,F) \wedge \neg\Diamond unsub(Y,F)) \Rightarrow \Diamond[ack(Y,F)\Big] \qquad (5)$$

- $$\Box\Big[(ack(Y,F) \wedge \neg\Diamond unsub(Y,F)) \Rightarrow \big(\Diamond pub(X,n) \wedge n \in N(F) \Rightarrow \Diamond notify(Y,n,X)\big)\Big] \qquad (6)$$

Correctness

A publish/subscribe system is *correct*, if it satisfies safety and liveness.

Distributed Implementation



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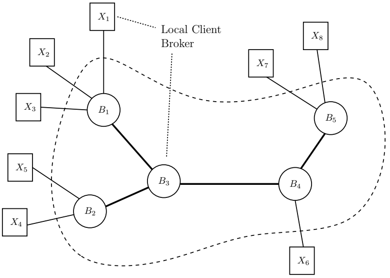

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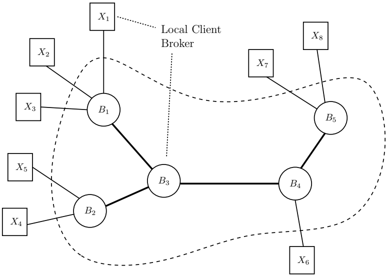

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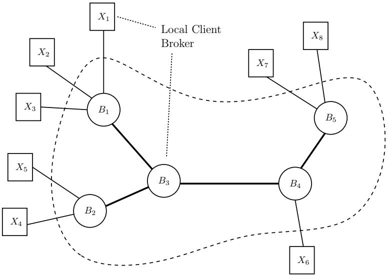

- Set of brokers $B_1, \ldots, B_n$ serving as access points.
- Brokers are concurrent processes cooperating by message passing.
- Each broker B manages a mutually exclusive set of local clients L_B and only communicates directly with its neighbor brokers N_B.

Assumptions

- Broker topology assumed to be acyclic.
- Channels are reliable (no corrupted, duplicated, lost, or spurious messages).
- Message latency is bounded.
- Communication with clients conceptually treated as message passing but assumed to be instantaneous.

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- Processing of *forward* and *pub* messages hardwired.
- Processing of *admin* messages is customized by implementing an instance of the `administer` procedure.

Notification Forwarding

- If a broker receives a *forward*(n) / *pub*(n) message from a neighbor / local client, it sends a *forward*(n) / *notify*(n) message to all neighbors / local clients D for which there is a routing entry (F, D) with $n \in N(F)$.

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- But a notification is never passed back to the neighbor it was received from.
- As the topology is acyclic, duplicate notifications are avoided.
- As every *notify*(Y, n) has a preceding *pub*(X, n), no spurious notifications are delivered.

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  - Routing with filter merging

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- implemented along the lines of formal framework
- based on microkernel architecture with routing component as kernel
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- ...Rebeca promises to become the first ever publish/subscribe system whose correctness can be formally proven!

Future Work

- Routing in cyclic topologies
- Funnel functions
- Fault tolerance
- Adaptivity
- Integration of routing and composite event detection
- Streaming operators
- Quality of Service

Thank You.

Questions?

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