# The Evolution of Internet-Scale Event Notification Services

## *Past, Present, and Future*

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# *The Evolution of Internet-Scale Event Notification Services*

- Past
  - *Event-Based Integration (EBI) occupied application niches, adapted to loosely-coupled systems*
  - *Event Notification Services (ENS) expanded their range, from hosts to LANs to WANs*
- Present
  - *Crossing trust domains raises new 'Internet' concerns*
- Future
  - *Explosion of diverse, competing protocol proposals*
  - *Selection criteria likely to lead toward convergence*

# Goals of this Presentation

- "You can't tell the players without a scorecard!"
  - Over a hundred systems and eighty more papers
- "What are the design choices?"
  - Identifying primary axes of classification
- "What's new research here?"
  - Issues which are truly unique to Internet-scale ENSs
- "What's going on in the marketplace?"
  - New players have wider ambitions than past ISENSs
- "How can we select more principled designs?"
  - Lessons from software architecture for ISENSs

# *Who We Are*

- Adam Rifkin
  - *Seventh-year at Caltech with K. Mani Chandy*
  - *Microsoft Research, HP Labs, Rome Labs, NASA*
  - *Studying the semantics of event models*
    - Can formal specification help explain the behavior and performance of distributed systems?
- Rohit Khare
  - *Second-year at UC Irvine with Richard Taylor*
  - *W3C, Web Journal, MCI Internet Architecture*
  - *Studying the design of application-layer protocols*
    - How did all these TPs evolve? Are they converging?

# Past, Present, Future

**Adapting to niche applications**

**Expanding range**

# *The Evolution of Event Systems*

- Defining Events, Notifications, and Handlers
  - *Enumerating and clustering existing systems*
- Evolution into new niches and widening range
- Archetypal applications and notification services
- Taxonomy of ENS design space
  - *Evaluating models from the literature*

# Defining our terms

- People have called lots of things event systems:
  - *graphical interfaces, physical simulations, collaborative workflow, programming with callbacks...*
- *Events* are *Notifications* to be *Handled*
  - *Events, as in physics, are abstract and instantaneous*
  - *Notifications are messages with definite semantics*
  - *Handlers implement synchronization and semantic constraints of a pattern of notifications*
- Events are *not*: RPC, Blackboards, Pipes, Documents, or FYI Messages

# Things that go “notify” in the night:

ACA (Digital)
Active Databases
Active Software
Actors
Amalgame
Amiga REXX
AppleEvents
Atlantis
Backweb
Bart
BEA/Tuxedo
BLIP
BOF/BOCK
C2 Style
CISCO Pub & Sub
COM+ Events
Consul
CORBA Notification
CORBA Transaction
Cronus
Desert
DCE RPC
DEEDS
DHCP
DIS (IEEE 1278)
Discrete Event Sim
DNS Notifications
DRP (Marimba)
DSN (mail)
East
e-cast (Lucent)
Elvin
ENP (Oracle)
Ensemble
Field
finger
GENA (MS)
FUSE
HORUS
HTTP
ICQ
iFlame
Information Bus
Infospheres
Intermind
Iona OrbixTalk
IP Multicast
IRC
ISIS
Java AWT
Java Beans
Java Distr. Events
Java InfoBus
Java OS events
Java Transactions
JavaSpaces
JEDI
JFC (Swing)
Keryx (HP)
Leases
Logical Clocks
Maisie
Majordomo
Mariposa
Mediator Pattern
Mentat
MFTP
MMS
MSMQ
MQ*Series
MTP
MTS
NNTP
NSTP
OpenDoc
PIPR
PLAN
Pointcast
POLYLITH
RIP
RMP
RPC
RVP
SGAP
SIMNET
SIENA
SIP
SMTP
SNMP Traps
SoftBench (HP)
SRM
SWAP
SwitchWare
Talarian
Taligent
Talkd
Teamwave
Tibco
ToolTalk (Sun)
Ubique
Vitria
VMTP
WhoDP
Win32 events
X Windows
Yahoo Pager
Yeast
Zephyr

# Clustering by Application Context

**Messaging**
Backweb
DRP (Marimba)
DSN (mail)
e-cast (Lucent)
HTTP
Intermind
Majordomo
MFTP
MSMQ
MQ*Series
NNTP
Pointcast
SMTP
SNMP Traps
Talarian
Teamwave
Tibco
VMTP

**Presence**
Blip
finger
ICQ
NSTP
PIPR
RVP
SGAP
SIP
WhoDP

**Chat**
iFlame
IRC
Talkd
Ubique
Yahoo Pager
Zephyr

**Simulation/Graphics**
Actors
DIS (IEEE 1278)
Discrete Event Sim.
Java AWT
JFC (Swing)
Living Worlds (HP)
Logical Clocks
Maisie
Mentat
SIMNET
Taligent
Win32 events
X Windows

**Application Integration**
ACA (Digital)
Active Software
Amalgame
Amiga REXX
AppleEvents
BEA/Tuxedo
East
Field
HORUS
Information Bus
Iona OrbixTalk
Java Beans
Java InfoBus
Keryx (HP)
OpenDoc
POLYLITH
SoftBench (HP)
SWAP
ToolTalk (Sun)
Vitria
Yeast

# Clustering by Notification Features

- Myriad ways to slice and dice this survey set…

**Low Latency**
COM+ Events
Amiga REXX
AppleEvents
SNMP Traps
IRelay Chat (IRC)

**High Latency**
SMTP
Majordomo
DSN (mail)
DNS Notifications
NNTP

**Polling**
Backweb
Finger
ICQ
Pointcast
Yahoo Pager

**Invocation**
CORBA Notification
Field
SoftBench (HP)
ToolTalk (Sun)
Zephyr

**Multicast**
IP Multicast
RMP
SIP
SRM
Tibco

**UDP Mode**
BackWeb
WhoDP

**Reliable**
BEA/Tuxedo
CORBA Transaction
MSMQ
MQ*Series

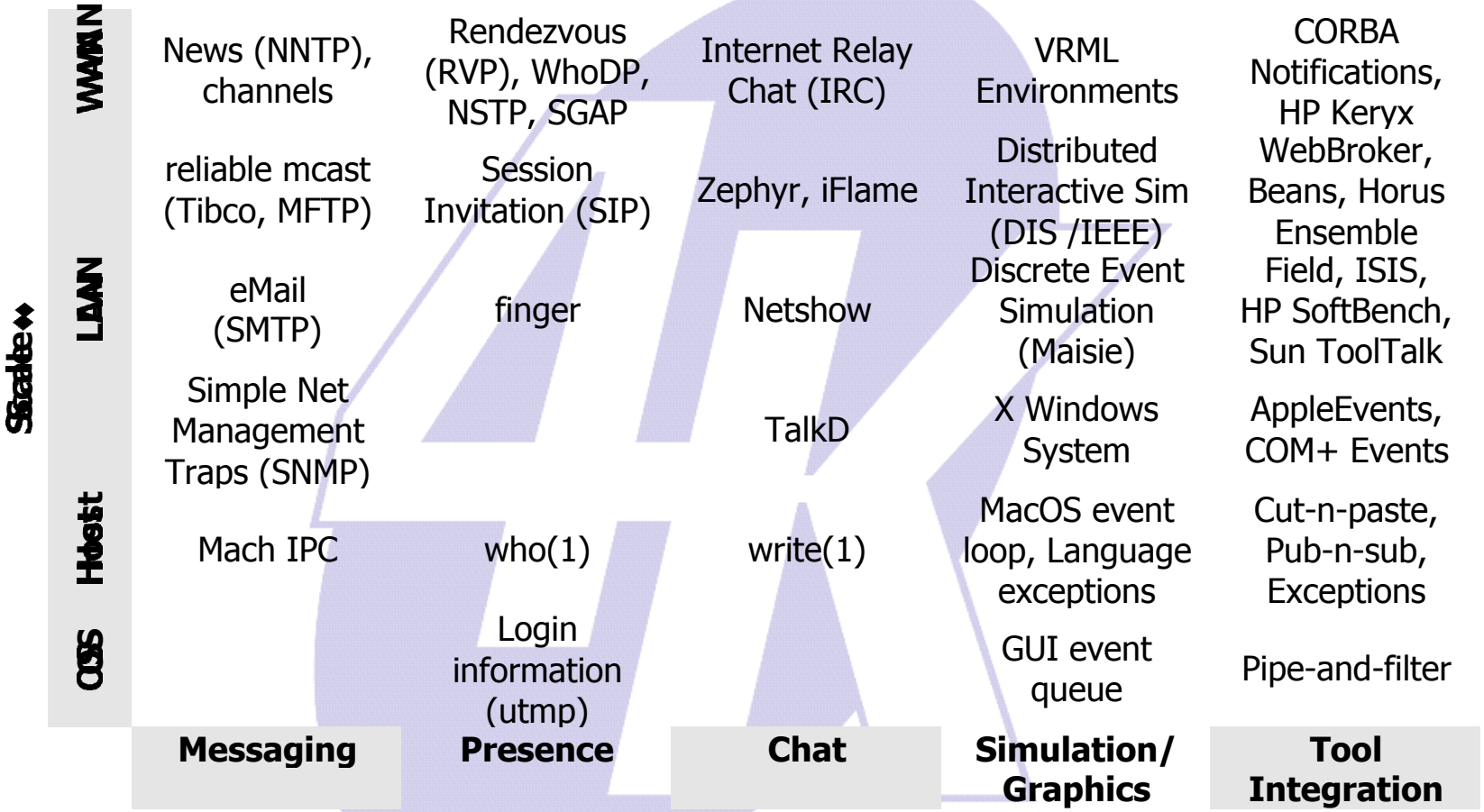
**Leases**
DHCP
AFS Caching
WebDAV

**Dead-reckoning**
DIS (IEEE 1278)
SIMNET
WhoDP

| | **1** | **N** |
|---|---|---|
| **1** | TalkD<br>Win32 events<br>X Windows | Backweb<br>Pointcast<br>DRP (Marimba)<br>Finger |
| **N** | Zephyr<br>SMTP | ICQ<br>Yahoo Pager<br>WhoDP<br>SGAP<br>NNTP |

| | **K** |
|---|---|
| **1** | C2 Style<br>DNS Notifications<br>DHCP<br>SMTP<br>SNMP Traps<br>Tibco |
| **K** | iFlame<br>Majordomo |

# The Evolutionary March of Progress: New niches and widening range…



# *Exploring the Fossil Record*

- Our evolutionary map is only descriptive as yet
  - *These five applications are* not *a privileged frame of reference; merely popular clusters*
- To evaluate EBI styles, outline orthogonal axes:
  - *Rate of event occurrence*
  - *Topology of notification distribution*
  - *Content model of notifications*
  - *Naming model: sources, sinks, queues, subscriptions*
  - *Event transformations: filtering, aggregation, etc.*
  - *Security and Privacy requirements*

# Application: Messaging

- Goal: Delivering “human-actionable” content
  - *News occurs at O(minutes) to O(days)*
  - *Sample event: “Today’s lunch menu is…”*
- Distributed 1-N (many) or 1-K (known set)
- Notifications range from text to multimedia
- Names: mailboxes, newsgroups, topics, etc.
- Transformations: compression, batch delivery
- Authenticated senders, content integrity & confidentiality

# *Systems: Messaging*

- E-mail and mailing lists
  - *Mail can be queued at relays; reliable, but O(days)*
  - *Mlists require subscriber verification; allows digests*
- USENET News
  - *Articles, named by message-ID, can be posted to a set of groups within a distribution region until expiry*
- Publish & Subscribe
  - *Topic selection can be more specific than "group", such as selection of characteristics of the messages*
- Web Push / "Channels"
  - *Poll for updated content; could be bundled, cached*

# Application: Presence

- Goal: maintaining awareness of people, devices
  - *Changes in state occur on O(minutes)*
  - *Sample Event: "Elvis has left the building…"*
- Monitor "buddies" or "editors" (1-K)
  - *Infrastructure typically designed for N-N, though*
- Notifications can be lightweight (text)
- Names: users-from-directories, groups
- Transformations: batch update; state timeout
- Privacy requires knowing who's watching

# Systems: Presence

- who (1), utmp
  - *Multiuser OSes log and report current logins*
- finger
  - *Returns last-seen, last-read, and .plan for username*
- WhoDP
  - *Switchboards maintain directory of clients; actual presence traffic redirected peer-to-peer*
- AOL Instant Messenger
  - *Centralized state server; client holds connection open*

# Application: Chat

- Goal: Delivering units of (human) conversation
  - *Interaction occurs on O(seconds)*
  - *Sample event: "[Duke] smells a Wumpus…"*
- Distributed 1-1, 1-K (lecture), or K-K (forum)
- Notifications range from text to multimedia
- Names: email addrs, handles, channels
- Security: speaker authentication, confidentiality through content encryption
- Privacy: audience enumeration

# Systems: Chat

- write (1)
  - *Displays to all users (except users blocking all writes)*
- TalkD
  - *Binary session request; requires active confirmation*
- Zephyr
  - *Delivers messagegrams with Kerberos authentication*
- Internet Relay Chat (IRC)
  - *Directed acyclic graph of servers using a 'gossip' alg.*
  - *Weak confidentiality of forum content (passwords)*
  - *Robots can automatically trigger events (invitations)*

# Application: Simulation

- Goal: Maintaining consistent (physical) state
  - *Interaction occurs on O(milliseconds)*
  - *Sample event: "[Duke] fires 9mm at the Wumpus…"*
  - *Sample event: "Mouse button 2 clicked twice…"*
- Distribution limited to 1-1 or small K-K groups
- Notifications are usually small and stateful (for example, delta updates)
- Transformations: event aggregation, masking (filtering), batching, and dead-reckoning

# *Systems: Simulation*

- GUI event queues
  - *Hardware devices deliver interrupts or are scanned, foreshadowing the invoke vs. poll options*
  - *Event queue can select events by bounds, type, etc.*
  - *Events can be updated, coalesced in the queue*
- Distributed Interactive Simulation (DIS)
  - *IEEE Standard 1278.1 (1995)*
  - *Physical and synthetic players in a wargame*
  - *Myriad specific update message formats*
  - *Lost updates replaced by predictions*

# Application: Integration

- Goal: wiring together component software
  - *Data flows from O(milliseconds) to O(hours)*
  - *This wide range can be problemmatic*
  - *Sample Event: “Compiler finished foo.c as foo.o”*
- 1-K; source usually unaware of consumers
- Notifications typically machine-readable streams
- Names: processes, hosts
- Transformations: data type adaptors

# Systems: Integration

- Information Bus
  - *Routes messages to groups based on content*
- POLYLITH Software Bus
  - *Redirects/repackages intermodule calls per bus wiring*
- Field, Yeast
  - *Central message repository triggers sw tools*
- AppleEvents, REXX
  - *Event-oriented user interface scripting languages*

# Developing an Architectural Model

- Zooming out from these details, we choose to separate the event infrastructure layer
- Above, applications rely on EBI services
  - *Several classic papers speak to this model*
- Below, EN services bound protocol designs

| | |
|---|---|
| Event Based Integration | Components/Tools, Connectors, Notifications, Requests<br>'Logical' routers, message transformers, application event semantics (e.g. dead-reckoning)<br>Reliable storage, synchronization, typing |
| Event Notification Services | Quality of Service, Link and message security<br>'Physical' routing topology, 'physical' naming, initiation rules (poll vs. interrupt)<br>Wire formats, stateful optimizations (session vs. packet), batching |

# *Field* *[Reiss90]*

- Connects clients (“tools”) with anonymous bcast
- Central message server as a separate process
- Tools register interest in message-expressions
- Forwarded in order received
- No exception handling
  - *e.g. access control, delivery constraint violations*
- Policy tool can intercept, replace messages
- “tools advertise operations” informed SoftBench

# Polylith [Purtilo94]

- Tools bind their I/O ports to a Software Bus
  - *ports identified by name, allowing retargeting*
- Module Interconnection Lang to wrap tools
- Simple, Structured, and Pointer message types
- Limited to simple filtering on channels
- No explicit support for groups
- No exception handling
  - *e.g. ill-formed messages or incompatible connections*

# EBI Framework [Barrett, et al 96]

| Feature | FIELD | POLYLITH | CORBA |
|---|---|---|---|
| Message Types | String | Simple, Structured, Pointer types | Simple, Structured, and Interface types |
| Registrar | Msg message server | Bus | ORBs |
| Router | Msg pattern matching | Bus | ORBs |
| Message Sending | Multicast | Point-to-Point, Multicast | Point-to-Point |
| Message Delivery | Non-polling (passive) | Polling (active) | Unspecified |
| Message Transform Functions (MTFs) | Filters, Policies | Filtering by bus channel | None |
| Delivery Constraints | Policy Priorities | Not User-definable | At-most-once, Best-effort |
| Grouping | Participant Groups | None | Participant and Router Groups ("domains") |

Presents a taxonomy of causes, not effects

# C2 Style [Taylor, et al 96]

- *Components* respond to notifications, emit requests (asynchronously)
- *Connectors* coordinate all communication
  - *First-class objects, function as routers, broadcasters, filters, prioritizers*
- *Messages* = name + typed parameters
- *Notifications* of state changes flow “down”
- *Requests* for action flow “up”

# ISE Observation and Notification [Rosenblum, Wolf 97]

- Attributes of 'Internet-Scale'
  - *Geographical reach, autonomy, security, QoS*
- Lifecycle of an event
  - Determination *of which events shall be observable*
  - Expression *of interest in an event or pattern*
  - Occurrence *of an event*
  - Observation
  - Relation *of an event to a pattern of interest*
  - Notification *to an application*
  - Receipt *by the application*
  - Response *of the application*

# *Framework* *[Rosenblum, Wolf 97]*

- *Object model* of senders and receivers
- *Event model* characterizes event phenomena
- *Naming model* of references to items of interest
- *Observation model* of identifiable patterns
- *Time model* of events causing notifications
- *Notification model* of mechanisms to express interest and receive them
- *Resource model* for allocation and accounting

# Moving to the Lower Layer: The ENS Design Space

- It isn't easy. Confusion abounds:
  - *"A Rendering may be received in one of two ways: either… returned as a value from a synchronous call ['client-pull'], or… requested and then sent asynchronously, in chunks ['server-push']" -- HTTP-NG Interfaces*
  - *"Messages that represent commands must be synchronous and must provide the caller with a reply." -- Field*
- Often conflate blocking, synchronization, timing, and initiation -- these are all separable

# Our Taxonomy of ENS Design Space

- Initiation
  - *Source- (interrupt) vs. Sink-initiated (poll)*
- Synchronization
  - *Synchronous (batched) vs. Asynchronous (deferred)*
- Blocking
  - *Blocking vs. Non-blocking handlers*
- Causality
  - *Ordered vs. unordered, duplicate, and/or missing*
- Timing (may be a spectrum)
  - *Real- (deadlined) to Virtual-time (eventual) delivery*

# Secondary Taxonomy Concerns

- Transport
  - *Reliability above vs. at the bearer service*
  - *Multicasting above vs. at the bearer service*
- Notification Content Model
  - *Externally-visible typing (MIME encodings)*
  - *Size*
  - *Streamable*
  - *Lossy content (multimedia)*
- Security
  - *Trusted event notifiers vs. trusted notifications*

# Past, Present, Future

## Crossing trust domains

# *Why Event-Based Integration won*

- Loose coupling is a hallmark of Internet-scale development
- Allows dynamic communication topology
- Separates engineering tradeoffs for latency, efficiency
- But, these were mission-specific and not yet Internet-Scale...

# *New issues*

- Not merely about scaling across space, time, and number of participants and events...
- …but across Organizations:
  - *Security concerns*
  - *Interoperability*
  - *Semantic (Ontological) agreement*
  - *Administrative Decentralization*
  - *Mobility*
- Most of all, *Evolvability* of an ISEN Service
  - *… we have an opportunity to define a generic service*

# *Unaddressed issues*

- Performance models: nonexistent
  - *We believe a model would converge with messaging performance, modulo "event-handling" time*
  - *Parameters such as event frequency, size, ...*
- Queuing policies across a connection topology
  - *Critical factor in scaling, yet usually unspecified in protocols*
- Evaluation criteria
  - *Scenarios, benchmarks, metrics, models*
- Others?

# Past, Present, Future

**Competing protocol proposals**

**Selection criteria**

# *The great thing about standards is...*

- At WISEN alone:
  - *Presence/Chat*
    - NSTP/SGAP/RVP/WhoDP
  - *Tool Integration*
    - SWAP/DAV/IPP
  - *Generic Notification Services*
    - GENA/BLIP
- Lots of others in the quiet race to market
- Does this welter of proposals overlook anything?

# *Perhaps.*

- "Connectors should be first-class objects"
  - *Don't hide subscription and queueing*
- "Transport is an engineering decision"
  - *… not a semantic one*
  - *Beware of "reliable" datagrams and multicast*
    - reinvent TCP and risk ACK implosion, respectively
- "With security aforethought"
  - *Need security at the message level*
- *If we are aiming at a global infrastructure, community involvement is paramount*

# Our Conclusions

## Revisiting our goals

# *"You can't tell the players without a scorecard!"*

- A staggering range of systems can be considered event-oriented
  - *Events are notifications which trigger commands*
- Need to tease apart EBI applications from ENSs
  - *In the past, EN systems presented both together*

# *"What are the design choices?"*

- We believe event notifications across the Internet are necessarily identifiable as messages
  - *ISEN design space is slightly larger than IS messages*
- Message delivery initiated by source or sink
  - *Polling vs. Interrupts*
    - often conflated with non-blocking vs. blocking semantics
    - often conflated with which-side-establishes-a-connection
- End-to-end delivery or via mediators (queues)
    - often conflated with "real time" vs. deferred
- Reliable delivery provided by or above transport

# *"What's new research here?"*

- Evolvability: how flexible can an ISENS be?
  - *An opportunity to build "great infrastructure"*
- Security: should the ENS be trusted or not?
  - *Hop-by-hop trust may not be dynamic enough*
- Performance modeling: what are the limits?
  - *Analytic and statistical models not developed yet*
- There's also good engineering to be done…
  - *(Not to mention standardization leadership)*

# *"What's going on in the market?"*

- New applications and protocols are emerging for EBI and ENS across organizational (trust) lines
- Entrants usually leveraging a technology
  - *Transport (UDP, mcast) or HTTP or both*
- Some glimmer of a layered solution
  - *Event notification separable from event schema*
- Collaboration and groupware tools are leaders

# *"How can we select more principled designs?"*

- We believe the C2 and "representational state transfer" architectural styles show promise
- C2's connectors, components, and notifications:
  - *can model (bridge) a range of current proposals*
  - *hint at design rules for verifying EBI*
  - *reuses a common ENS at varying levels of abstraction*
  - *perhaps a lattice of event notification services*
- Representational State Transfer's messages
  - *separate the artifact (wire) and ideal (remote) form*
  - *allow dynamism and scale through statelessness*

# Recommendation: A Layered ISENS

- Wire protocol for notifications
  - *Perhaps an "asynchronous HTTP"*
- Notification management
  - *Interfaces for advertising and subscribing*
  - *Queue management policies*
  - *Generic notification typing*
- WebEvents Package
  - *Trapping HTTP Method × Resource*
  - *Link maintenance*
  - *New-content ("push")*
- These are missing from current proposals!

# For Further Information…

- NOTIFY BOF at IETF-Chicago
  - *Chaired by Jim Whitehead, UC Irvine*
- This presentation and our events bibliography
  - *http://www.cs.caltech.edu/~adam/isen/*
- Notifications mailing list
  - *notification-subscribe@makelist.com*
  - *http://www.findmail.com/list/notification/*
- Contact us
  - *adam@cs.caltech.edu*
  - *rohit@uci.edu*