Bloom Filter Based Routing for Content-Based Publish/Subscribe

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Event forwarding ([CRW01]: siena, [TK06]: forest)
Subscription routing ([CRW01]: siena, [TK06]: forest)
Motivation

- Efficient End-to-End transmission delays
- More flexible edge routing approach [JF07]
- A flexible communication substrate for event processing systems
Our Contributions

- New routing structures and algorithms:
  - applicable for both traditional and edge routing
  - `sbsposet` – predicate storage and coverage
  - `sbstree` – management of disjunctions of predicates
  - conjunctions

- Content summarisation using Bloom filters [Blo70]
  - not imposing any limitation on the type and content of the events/subscriptions
  - sparse Bloom filters for space complexity
Our Contributions

- New routing structures and algorithms:
  - applicable for both traditional and edge routing
  - **sbsposet** – predicate storage and coverage
  - **sbstree** – management of disjunctions of predicates and conjunctions

- Content summarisation using Bloom filters [Blo70]
  - not imposing any limitation on the type and content of the events/subscriptions
  - sparse Bloom filters for space complexity
Publish/Subscribe Model

- Decoupled [EFGK03] communication...
  - ...between publishers and subscribers via routers
  - ...using subscriptions (conjunction of predicates)
  - ...and events (disjunction of predicates)
  - ...based on their content
Publish/Subscribe Model

- Decoupled [EFGK03] communication...
- ...between publishers and subscribers via routers
  - ...using subscriptions (conjunction of predicates)
  - ...and events (disjunction of predicates)
  - ...based on their content
Publish/Subscribe Model

- Decoupled [EFGK03] communication...
- ...between publishers and subscribers via routers
- ...using subscriptions (conjunction of predicates)

\[
\begin{aligned}
\{ & \text{movie} = "star wars" \quad \text{AND} \quad \text{price} < 15 \\
& \quad p_0() \quad \text{AND} \quad p_1() \}
\end{aligned}
\]

- ...and events (disjunction of predicates)
- ...based on their content
Publish/Subscribe Model

- Decoupled [EFGK03] communication...
- ...between publishers and subscribers via routers
- ...using subscriptions (conjunction of predicates)
- ...and events (disjunction of predicates)

\[
\begin{align*}
\text{movie} &= "batman" \\
\text{price} &= 15.5
\end{align*}
\]

...based on their content
Publish/Subscribe Model

- Decoupled [EFGK03] communication...
- ...between publishers and subscribers via routers
- ...using subscriptions (conjunction of predicates)
- ...and events (disjunction of predicates)
- ...based on their content
Event forwarding

An event $e$ matches a subscription $s$ ($e \preceq s$)

$$\forall p \in s \quad \exists \{an, av\} \in e : \quad p(\{an, av\}) = \text{true} \quad (1)$$

A broker contains $|S|$ subscriptions:

$$\forall s \in S : \quad \text{execute Equation 1} \quad (2)$$
Approach

An event $e$ matches a subscription $s$ ($e \preceq s$)

$$\forall p \in s \exists \{an, av\} \in e : p(\{an, av\}) = true$$

Evaluate predicate functions
Approach

An event $e$ matches a subscription $s$ ($e \prec s$)

$$\forall p \in s \quad \exists \{an, av\} \in e : \quad p(\{an, av\}) = \text{true}$$

Calculate of disjunction of conjunctions of predicates
Overview: Subscription Routing

Bloom Filter Based Routing for Content-Based Publish/Subscribe

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Overview: Subscription Routing

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Overview: Subscription Routing

Motivation

Background & Overview

SBSPoset & SBSTree

Evaluation

Summary

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Overview: Subscription Routing

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Overview: Subscription Routing

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Overview: Event Forwarding

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Bloom Filter Based Routing for Content-Based Publish/Subscribe

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SBSPoset

- Stores subscriptions as:
  - disjunction of single predicates
  - ordered by the coverage relation
- Every predicate is assigned a Bloom filter
  - which summarizes its content
  - and that of covering predicates
- No limitations on the expressiveness of the subscription/event language
SBSPoset: subscription storage

x
null
≥0.7
{2787, 12518}
>5
{2787, 6066, 8581, 12518}

y
null

<5

=0

{5037, 8516}
{5001, 5037, 8507, 8516}
**SBSPoset: subscription storage**

New subscription: \( x > 15 \) \( y > 0 \)

- **SBSPoset**:
  - Subscription storage
  - \( x > 15 \)
  - \( y > 0 \)
  - \( x = \text{null} \)
  - \( y \geq 0.7 \)
  - \( >5 \) \( <5 \)
  - \( =0 \)
  - \( \{2787, 12518\} \)
  - \( \{2787, 6066, 8581, 12518\} \)
  - \( \{5037, 8516\} \)
  - \( \{5001, 5037, 8507, 8516\} \)

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**SBSPoset: subscription storage**

New subscription:

\[ x > 15 \quad y > 0 \]

- \( x \geq 0.7 \)
- \( x > 5 \)
- \( x \leq 5 \)
- \( y \geq 0 \)
- \( y > 0 \)
- \( y = 0 \)
SBSPoset: subscription storage

New subscription:

\[ x > 15 \quad y > 0 \]

\[ \{5001, 5037, 8507, 8516\} \]
SBSPoset: subscription storage

New subscription:

\( x > 15 \) \( y > 0 \)

- \( x \): null
- \( y \): null

- \( x \): \( \geq 0.7 \)
  - \( \{2787, 12518\} \)
  - \( \{2787, 6066, 8581, 12518\} \)
- \( y \): \( > 5 \)
  - \( \{6441, 10582\} \)
  - \( \{5102, 8636\} \)
- \( x \): \( > 15 \)
  - \( \{2787, 6066, 6441, 8581, 10582, 12518\} \)

- \( y \): \( = 0 \)
  - \( \{5001, 5037, 8507, 8516\} \)

- \( y \): \( \leq 0.7 \)
  - \( \{5037, 8516\} \)

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SBSPoset: subscription storage

New subscription:

- \(x > 15\) and \(y > 0\)
- \(\{5102, 8636\}\)
- \(\{5102, 8636\}\)

Tree structure:

- \(x\)
  - null
  - \(\geq 0.7\)
    - \(\{2787, 12518\}\)
    - \(>5\)
      - \(\{2787, 6066, 8581, 12518\}\)
    - \(>15\)
      - \{2787, 6066, 6441, 8581, 10582, 12518\}

- \(y\)
  - null
  - \(<5\)
    - \(\{5037, 8516\}\)
    - \(=0\)
      - \{5001, 5037, 8507, 8516\}
  - \(>0\)
    - \{5001, 5037, 8507, 8516\}

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SBSTree

- Represents the disjunction of conjunctions of subscriptions’ predicates:
  - stores only Bloom filters
SBSTree: subscription storage

New subscription: $x > 15$ and $y > 0$

Subscriptions:
- f4@dot.com
- f5@dot.com
- f1@dot.com
- f3@dot.com
- f2@dot.com

{6441, 10582} and {5102, 8636}
SBSTree: subscription storage

New subscription:

\[
\begin{align*}
x &> 15 \\
y &> 0
\end{align*}
\]

\{6441, 10582\} \quad \{5102, 8636\}
SBSTree: subscription storage

New subscription:

x > 15
y > 0

{6441, 10582}
{5102, 8636}
SBSPoset: event forwarding

Event: \( x=7 \) \( y=-2 \)

- \( x \)
  - null
  - \( \geq 0.7 \) \( \{2787, 12518\} \)
  - \( >5 \) \( \{2787, 6066, 8581, 12518\} \)
  - \( >15 \) \( \{2787, 6066, 6441, 8581, 10582, 12518\} \)

- \( y \)
  - null
  - \( <5 \) \( \{5037, 8516\} \)
  - \( =0 \) \( \{5001, 5037, 8507, 8516\} \)
  - \( >0 \) \( \{5102, 8636\} \)
SBSPoset: event forwarding

Event: \( x = 7 \) \( y = -2 \)

- \( x \)
  - null
  - \( \geq 0.7 \) → \{2787, 12518\}
  - \( > 5 \) → \{2787, 6066, 8581, 12518\}
  - \( > 15 \) → \{2787, 6066, 6441, 8581, 10582, 12518\}

- \( y \)
  - null
  - \( < 5 \) → \{5037, 8516\}
  - \( = 0 \) → \{5001, 5037, 8507, 8516\}
  - \( > 0 \) → \{5102, 8636\}
SBSPoset: event forwarding

Event: x=7, y=-2

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SBSPoset: event forwarding

Event: \(x=7\) \(y=-2\)

- **x**
  - null
  - \(\geq 0.7\)
    - \(\{2787, 12518\}\)
    - \(>5\)
      - \(\{2787, 6066, 8581, 12518\}\)
    - \(>15\)
      - \(\{2787, 6066, 6441, 8581, 10582, 12518\}\)

- **y**
  - null
  - \(<5\)
    - \(\{5037, 8516\}\)
  - \(>0\)
    - \(\{5102, 8636\}\)

Note: The diagram represents the structure and decision process for event forwarding in the context of SBSPoset.
**SBSPoset: event forwarding**

Event: \( x = 7 \) \( y = -2 \)

```
x
null
≥ 0.7
> 5
> 15
{2787, 12518}
{2787, 6066, 8581, 12518}

y
null
≤ 0.7
< 5
= 0
{5037, 8516}
{5001, 5037, 8507, 8516}

> 0
{5102, 8636}
```

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SBSPoset: event forwarding

Event:

- $x = 7$
- $y = -2$

Dataset:

- $\{2787, 6066, 8581, 12518\}$

Trees:

- **SBSPoset**
  - $x$:
    - null
    - $\geq 0.7$
    - $> 5$
    - $> 15$
    - $\{2787, 6066, 8581, 12518\}$

- **SBSTree**
  - $y$:
    - null
    - $< 5$
    - $= 0$
    - $> 0$
    - $\{5001, 5037, 8507, 8516\}$
    - $\{5102, 8636\}$

Bloom Filter Based Routing for Content-Based Publish/Subscribe

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SBSPoset: event forwarding

Event: \( x=7 \)
\{2787, 6066, 8581, 12518\}

Event: \( y=-2 \)
\{5037, 8516\}

\( x \geq 0.7 \)
\{2787, 12518\}

\( x > 5 \)
\{2787, 6066, 8581, 12518\}

\( x > 15 \)
\{2787, 6066, 6441, 8581, 10582, 12518\}

\( y \)
\{null\}

\( y < 5 \)
\{5037, 8516\}

\( y = 0 \)
\{5001, 5037, 8507, 8516\}

\( y > 0 \)
\{5102, 8636\}
SBSPoset: event forwarding

Event: \( x = 7 \) \( y = -2 \)

\[
\begin{align*}
&x \\
&\quad \rightarrow \text{null} \\
&\quad \downarrow \quad \geq 0.7 \\
&\quad \downarrow \quad > 5 \\
&\quad \downarrow \quad > 15 \\
&\{2787, 2506, 8581, 12518\} \\
&\quad \downarrow \quad \leq 0.7 \\
&\quad \downarrow \quad < 5 \\
&\quad \downarrow \quad < 0 \\
&\quad \downarrow \quad = 0 \\
&\quad \downarrow \quad \geq 0 \\
&\{5001, 5037, 8507, 8516\} \\
&\downarrow \\
&\{5102, 8636\}
\end{align*}
\]
SBSPoset: event forwarding

Event:
- $x = 7$
- $y = -2$

Evaluation:
- $x \geq 0.7$
- $x > 5$
- $x > 15$
- $x < 5$
- $x = 0$
- $x = 0$

- $y \geq 0.7$
- $y > 5$
- $y > 15$
- $y < 5$
- $y = 0$

- $\{5037, 8516\}$
- $\{2787, 6066, 8581, 12518\}$
- $\{2787, 6066, 8581, 12518\}$
- $\{2787, 6066, 8581, 10582, 12518\}$
- $\{5001, 5037, 8507, 8516\}$
- $\{5102, 8636\}$

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**SBSPoset: event forwarding**

Bloom Filter Based Routing for Content-Based Publish/Subscribe

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**SBSTree: event forwarding**

```
null

5037
  └── 8516
    └── f4@dot.com

5102
  └── 6441
    └── 8636
      └── f6@dot.com

5001
  └── 8507
    └── f5@dot.com

6066
  └── 8581
    └── f1@dot.com

6441
  └── 10582
    └── f3@dot.com

2787
  └── 12518
    └── f2@dot.com
```

Event: \( x=7 \) \( y=-2 \)

\( \{2787, 5037, 6066, 8516, 8581, 12518\} \)
SBSTree: event forwarding

Event: \( x=7 \) \( y=-2 \)

\{2787, 5037, 6066, 8516, 8581, 12518\}
SBSTree: event forwarding

null

5037
5102
5001
6066
6441
2787
8516
6441
8507
8581
10582
12518
f4@dot.com
f5@dot.com
f1@dot.com
f3@dot.com
f2@dot.com
8636
10582
f6@dot.com

Event: x=7, y=-2

{2787, 5037, 6066, 8516, 8581, 12518}
SBSTree: event forwarding

Event: $x = 7$, $y = -2$

{2787, 5037, 6066, 8516, 8581, 12518}
Evaluation Environment

- SIENA 1.5.4
- Apache Mina
- Stochastic Simulation in Java (SSJ) library
- BloomFilter
Evaluation Environment

- SIENA 1.5.4
- Apache Mina
  - http://mina.apache.org/
  - ver. 2.0.0-M1 as of 24th Jan 2008
- Stochastic Simulation in Java (SSJ) library
- BloomFilter
Evaluation Environment

- SIENA 1.5.4
- Apache Mina
- Stochastic Simulation in Java (SSJ) library
  - umontreal.iro.lecuyer.randvar.*
  - umontreal.iro.lecuyer.rng.*
- BloomFilter
Evaluation Environment

- SIENA 1.5.4
- Apache Mina
- Stochastic Simulation in Java (SSJ) library
- BloomFilter
  - http://wwwse.inf.tu-dresden.de/xsiena
  - Based on code by: Hongbin Liu and Arash Partow
Event forwarding

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Subscription routing

![Graph showing time vs. number of filters for different routing methods](image-url)

**Bloom Filter Based Routing for Content-Based Publish/Subscribe**

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TCP/IP Latency

The graph shows the latency in microseconds (µs) for different numbers of events and brokers. The x-axis represents the latency in microseconds, while the y-axis represents the number of events. The graph includes data for local and distributed brokers with 1, 2, and 3 brokers. The data indicates a decrease in latency with an increase in the number of brokers.
TCP/IP Throughput

Bloom Filter Based Routing for Content-Based Publish/Subscribe

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Local Throughput

![Graph showing local throughput with different distributions and event rates.](image-url)
False Positives

![Graph showing false positives vs. number of delivered events](image)

- % false pos, log₂m=12, k=4
- % false pos, log₂m=13, k=4
- % false pos, log₂m=13, k=5
- % false pos, log₂m=13, k=6

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Bloom Filter vs Sparse Bloom Filter

![Graph comparing memory consumption (KB) vs. number of elements inserted for Bloom filter and Sparse Bloom filter.](image)

- **Bloom filter** shows a flat line, indicating minimal memory consumption regardless of the number of elements inserted.
- **Sparse Bloom filter** shows a steady increase in memory consumption as the number of elements inserted grows.

- **Memory Consumption (KB)**
  - **Y-axis**: 10^3 to 10^6
  - **X-axis**: 0 to 120000

- **# Elements Inserted**
  - Increments: 0, 20000, 40000, 60000, 80000, 100000, 120000

---

**Bloom Filter Based Routing for Content-Based Publish/Subscribe**

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Summary

- Low latency, high throughput
- Event forwarding based on Bloom filters
- No restrictions on the subscription language
- Decoupled management of predicates and their conjunctions
Thank You!

http://wwwse.inf.tu-dresden.de/xsiena/
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