# Consistency Analysis in Bloom: A CALM and Collected Approach

Peter Alvaro, Neil Conway, William R. Marczak, Joseph M. Hellerstein

# Status Quo

Distributed programming: **increasingly common**

- Cloud computing, mobile
- No longer just for the experts!

Distributed programming: still **very difficult**

- Parallelism, asynchrony, partial failure, …

# Toward Disorderly Programming

Imperative languages are "ordered by default"

- Data: ordered array of cells
- Computation: ordered sequence of instructions
- This is a poor fit for distributed computing!

Instead: **disorderly programming**

- Data: unordered collections (sets)
- Computation: unordered bundle of declarative rules
- Ordering constructs provided *when needed*
- Success stories: MapReduce, parallel SQL

# Outline

1. A new language: **Bloom**
   – Disorderly programming for distributed systems
2. A set of analysis tools: **CALM**
   – When is ordering needed in a distributed program?

# Bloom

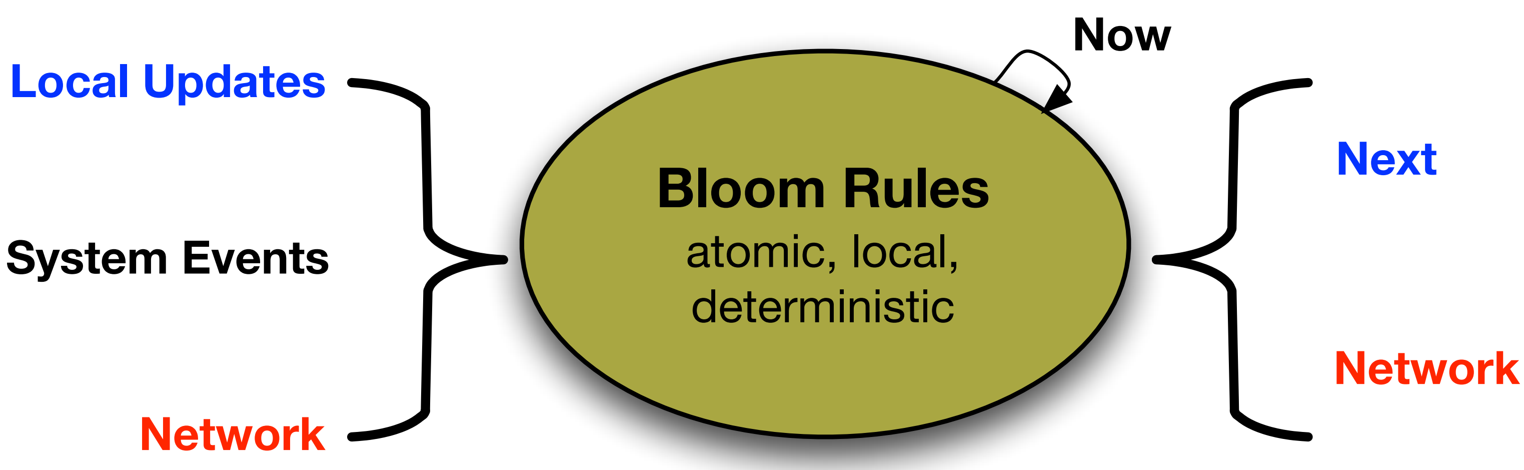
New language for distributed programming

- Prototype implementation as a Ruby DSL
  - Bud: “Bloom Under Development”
- Fully declarative semantics
  - Datalog + state update and asynchronous messages
- Rule-based language + some ideas from OOP
  - Abstract interfaces, modularity, encapsulation

# Operational Model

Basic primitives:

- Local computation (Datalog fixpoint)
- State update
- Asynchronous messaging



# Bloom Statements

`<collection>` `<temporal op>` `<expr>`

| | |
|---|---|
| **`table`** | persistent |
| **`scratch`** | transient |
| **`channel`** | network transient |
| **`periodic`** | scheduled transient |
| **`interface`** | interface transient |

| | |
|---|---|
| **`<=`** | now |
| **`<+`** | next |
| **`<-`** | delete (at next) |
| **`<~`** | async |

| |
|---|
| `map, flat_map` |
| `reduce, group` |
| `join, outerjoin` |
| `empty?, include?` |

# Abstract Delivery Protocol

```
module DeliveryProtocol
  include BudModule

  state do
    interface input, :pipe_in,
                       [:dst, :src, :ident] => [:payload]
    interface output, :pipe_sent,
                       [:dst, :src, :ident] => [:payload]
  end
end
```

# Best-Effort Delivery

Location Specifier

```
module BestEffortDelivery
  include DeliveryProtocol

  state do
    channel :pipe_chan, [:@dst, :src, :ident] => [:payload]
  end

  declare
  def snd
    pipe_chan <~ pipe_in
  end

  declare
  def done
    pipe_sent <= pipe_in
  end
end
```

# Reliable Delivery

```
module ReliableDelivery
  include DeliveryProtocol
  import BestEffortDelivery => :bed

  state do
    table :buf,
    [:dst, :src, :id] => [:payload]
    channel :ack, [:@src, :dst, :id]
    periodic :clock, 2
  end

  declare
  def do_send
    buf <= pipe_in
    bed.pipe_in <= pipe_in
  end

  declare
  def retry_timer
    do_retry = join [buf, clock]
    retry_msg = do_retry.map {|b, c| b}
    bed.pipe_in <= retry_msg
  end

  declare
  def rcv
    ack <~ bed.pipe_chan.map
    {|p| [p.src, p.dst, p.id]}
  end

  declare
  def done
    got_ack = join [ack, buf],
                   [ack.id, buf.id]
    msg_done = got_ack.map {|a, b| b}

    pipe_sent <= msg_done
    buf <- msg_done
  end
end
```

# Outline

1. A new language: Bloom
   – Disorderly programming for distributed systems
2. A set of analysis tools: CALM
   – When is ordering needed in a distributed program?

# Review: Monotonicity

**Monotonic Logic**

- The more you know,
  The more you know
- e.g., map, filter, join

**Non-Monotonic Logic**

- New inputs might require retracting previous conclusions
- To have a “certain” conclusion, must seal input set
- e.g., aggregation, negation

# Monotonicity and Order

**Monotonic:**

– Output is insensitive to message delivery order

**Non-Monotonic:**

– Ordering may be needed for consistent results
  - Everyone must agree on the contents of the input set
– Simple analysis: identify **points of order**
  - Non-monotonic operators fed by asynchronous messages

# Distributed Consistency

**Strong Consistency:**

– Enforce total order over messages
  - E.g., using Paxos, Two-Phase Commit, GCS, …

**Loose Consistency:**

– Write application to tolerate *any* sequence of message orderings
  - E.g., idempotent, commutative, associative operations
  - Application-specific compensation logic

# Practical Implications of CALM

**Strong Consistency:**

- Identify points of order without coordination logic
- Rewrite program to adjust points of order
  - Push coordination to “cheap” parts of the dataflow
  - Coordination as an optimization problem?

**Loose Consistency:**

- Track inconsistency “taint” through the program
  - Ensure that inconsistency is resolved by applying compensation logic

# Recap

1. Order is a scarce resource!
   – Help the programmer use it wisely
2. What is coordination *for*?
   – Consistent results from non-monotonic logic
3. Draw user's attention to points of order
   – Resolve via coordination or compensation
4. Bloom: pragmatic rule-based language for distributed programming

# More Info

http://bloom.cs.berkeley.edu

Bud: alpha release shortly

Initial writeups:

- CIDR'11 (overview, CALM)
- Datalog 2.0 (declarative semantics)
- PODS'11 (in submission)
- PODS'10 keynote (conjectures about CALM)

Thanks to:
MSR, IBM Research, Yahoo! Research, NSF, AFOSR

# Applying CALM: Coordination

- Given point of order, can we inject coordination logic automatically?
- Can we recognize equivalent choices for coordination?
  - Coordination strategy as an optimization problem

# Applying CALM: Compensation

- Taint tracking: ensure that before output of a point of order is used, it is resolved via compensation logic
- Memories, guesses and apologies (Helland)
  - Common pattern for loose consistency
  - How can we help the programmer?