Cloud Programming: From Doom and Gloom to BOOM and Bloom

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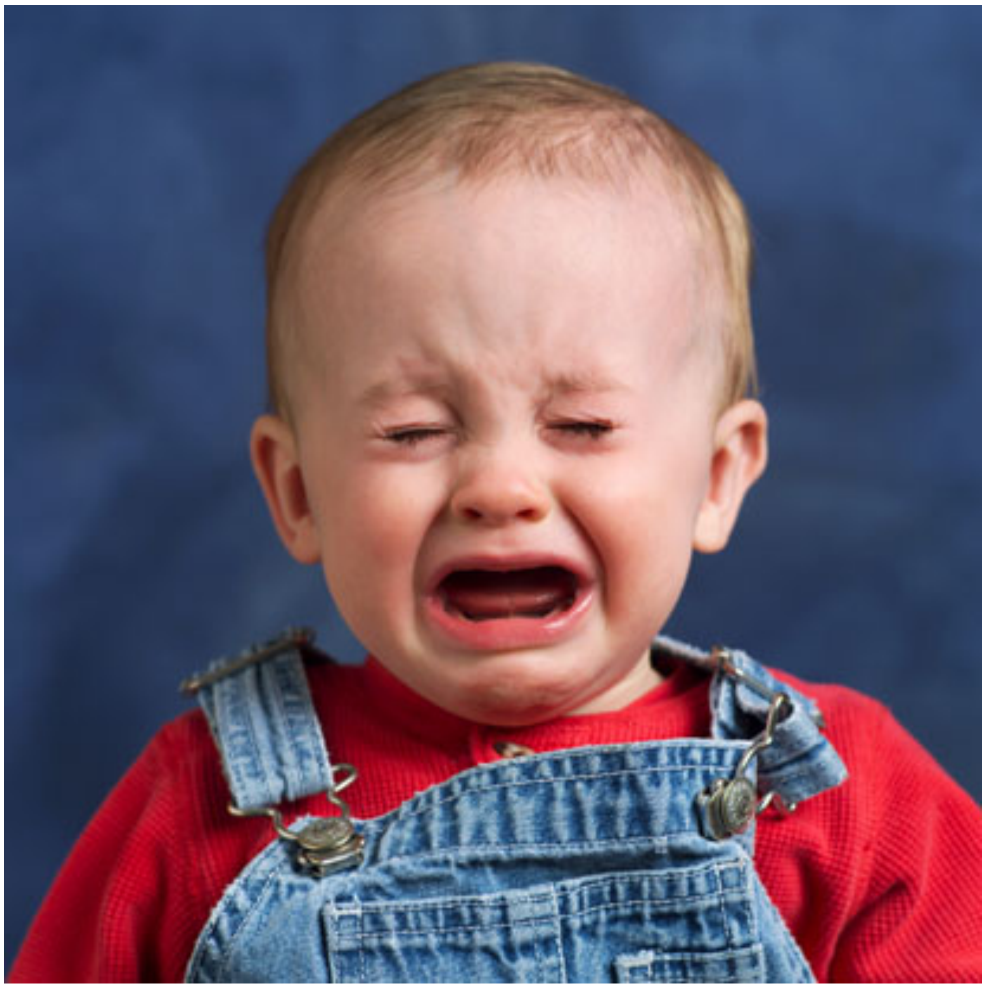
Datalog 2.0 Workshop

Cloud Computing: The Next Great Computing Platform

The Problem



Writing reliable, scalable distributed software remains **extremely difficult**.

Doom and Gloom!

"...when we start talking about parallelism and ease of use of truly parallel computers, we're talking about a problem that's as hard as any that computer science has faced .... I would be **panicked** if I were in industry."

-- John Hennessey, Stanford

A Ray of Light

- We understand **data-parallel** computing
  - MapReduce, parallel DBs, etc.
- Can we take a hard problem and transform it into an easy one?

Everything is Data

- Distributed computing is all about **state**
  - System state
  - Session state
  - Protocol state
  - User and security-related state
  - ... and of course, the actual “data”
- Computing = Creating, updating, and communicating that state

Datalog to the Rescue!

1. Data-centric programming
   – Explicit, uniform state representation: relations
2. High-level declarative queries
   – Datalog + asynchrony + state update

Outline

1. The **BOOM** Project
   - Cloud Computing stack built w/ distributed logic
   - BOOM Analytics: MapReduce and DFS in Overlog
2. **Dedalus**: Datalog in Time (and Space)
3. (Toward) The Bloom Language
   - Distributed Logic for Joe the Programmer

The BOOM Project

- **B**erkeley **O**rders **O**f **M**agnitude
  - OOM more scale,
    OOM less code
  - Can we build Google in 10k LOC?
- Build "Real Systems" in distributed logic
  - Begin w/ an existing variant of Datalog ("Overlog")
  - Inform the design of a new language for distributed computing (Bloom)

BOOM Analytics

- Typical "Big Data" stack: MapReduce (Hadoop) + distributed file system (HDFS)
- We tried two approaches:
  - HDFS: *clean-slate* rewrite
  - Hadoop: replace job scheduling logic w/ Overlog
- Goals
  1. Replicate existing functionality
  2. Add Hard Stuff (and make it look easy!)

Overlog: Distributed Datalog

- Originally designed for routing protocols and overlay networks (Loo *et al.*, SIGMOD'06)
  - Routing = recursive query over distributed DB
- Datalog w/ aggregation, negation, functions
- Distribution = horizontal partitioning of tables
  - Data placement *induces* communication

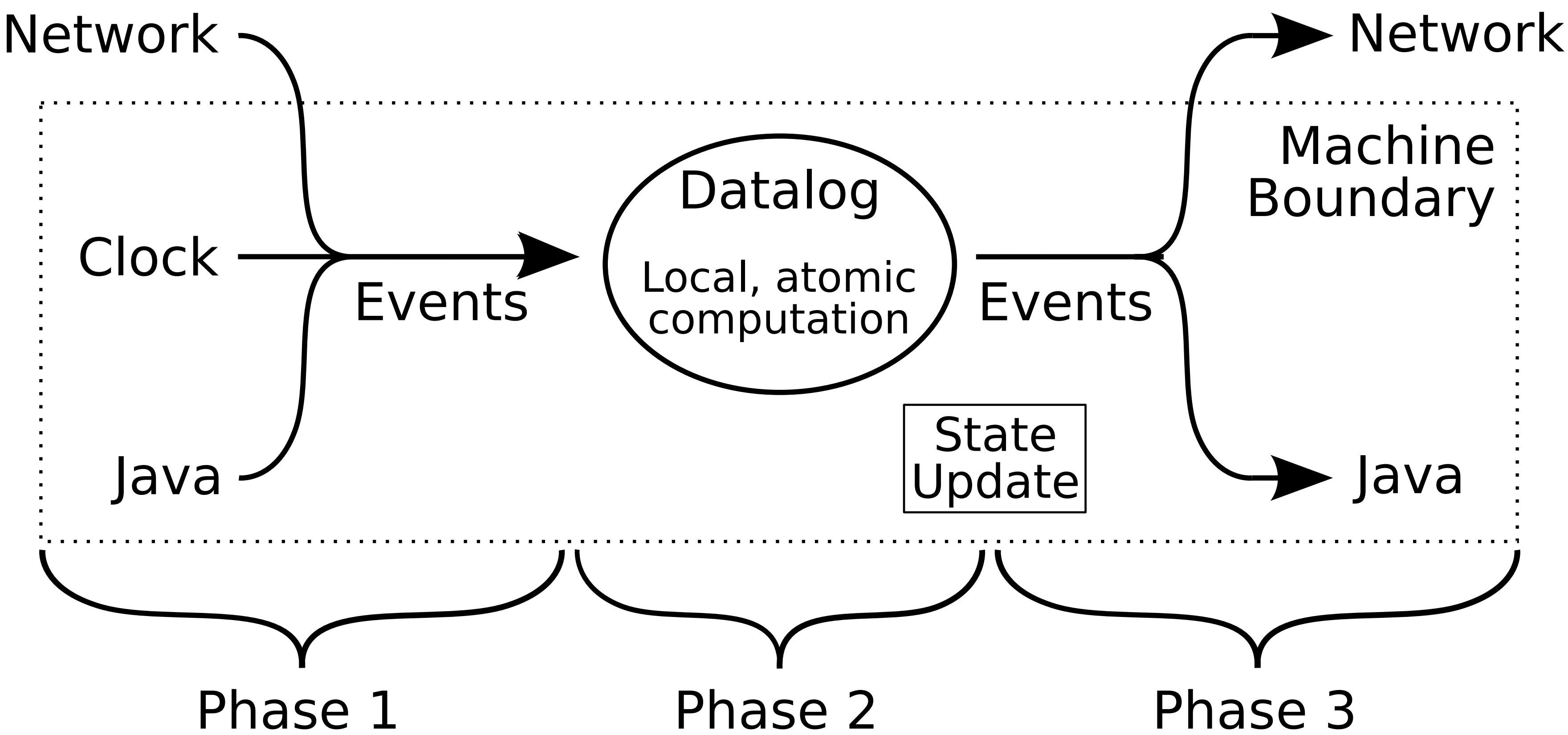
Yet Another Transitive Closure

```
link(X, Y, C);
path(X, Y, C) :- link(X, Y, C);
path(X, Z, C1 + C2) :- link(X, Y, C1),
                       path(Y, Z, C2);
mincost(X, Z, min<C>) :- path(X, Z, C);
```

Overlog Example

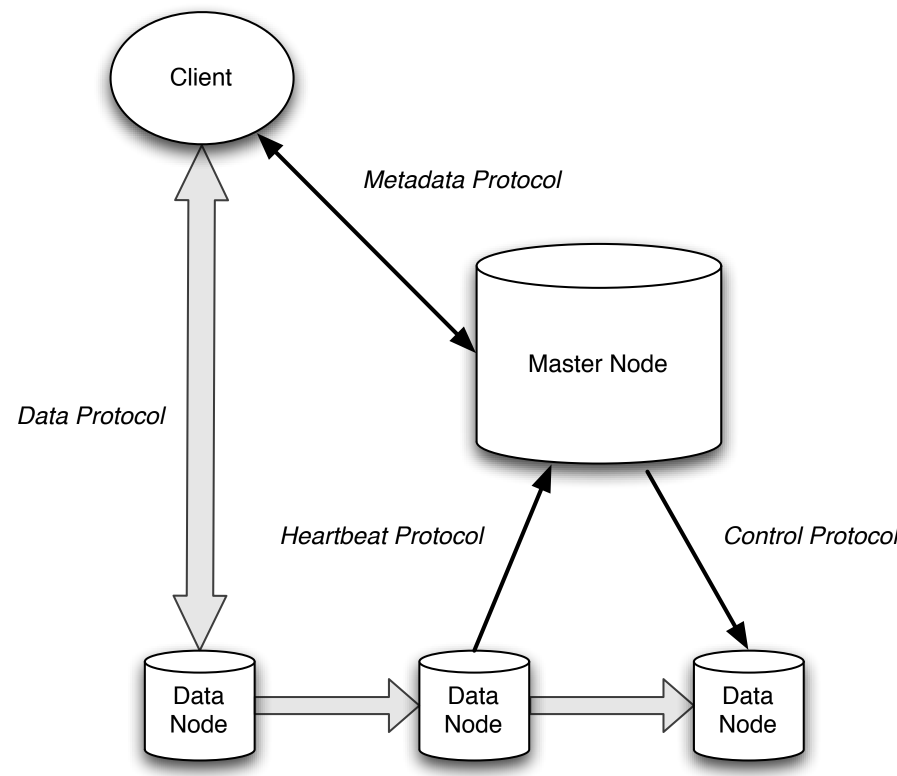
```
link(@X, Y, C);
path(@X, Y, C) :- link(@X, Y, C);
path(@X, Z, C1 + C2) :- link(@X, Y, C1),
                        path(@Y, Z, C2);
mincost(@X, Z, min<C>) :- path(@X, Z, C);
```

Overlog Timestep Model



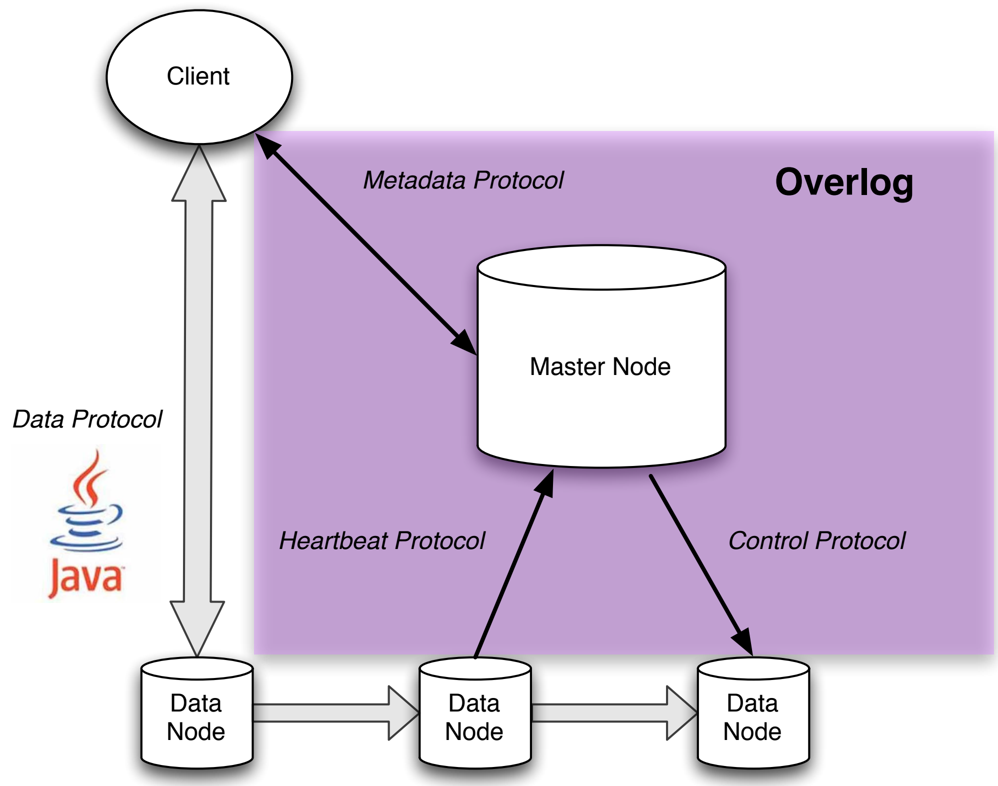
Hadoop Distributed File System

- Based on the Google File System (*SOSP'03)*
  - Large files, sequential workloads, append-only
  - Used by Yahoo!, Facebook, etc.
- Chunks 3x replicated at data nodes for fault tolerance



BOOM-FS

- Hybrid system
  - Complex logic: Overlog
  - Performance-critical (but simple!): Java
- Clean separation between policy and mechanism



BOOM-FS Example: State

Represent file system metadata with relations.

Name	Description	Attributes
file	Files	fileID, parentID, name, isDir
fqpath	Fully-qualified path names	fileID, path
fchunk	Chunks per file	chunkID, fileID
datanode	DataNode heartbeats	nodeAddr, lastHbTime
hb_chunk	Chunk heartbeats	nodeAddr, chunkID, length

BOOM-FS Example: Query

Represent file system metadata with relations.

```
// Base case: root directory has null parent
fqpath(FileId, Path) :-
    file(FileId, FParentId, FName, IsDir),
    IsDir = true, FParentId = null, Path = "/";

fqpath(FileId, Path) :-
    file(FileId, FParentId, FName, _),
    fqpath(FParentId, ParentPath),
    // Do not add extra slash if parent is root dir
    PathSep = (ParentPath = "/" ? "" : "/"),
    Path = ParentPath + PathSep + FName;
```

BOOM-FS Example: Query

Distributed protocols: join between event stream and local database

```
// "ls" for extant path => return listing for path
response(@Source, RequestId, true, DirListing) :-
    request(@Master, RequestId, Source, "Ls", Path),
    fqpath(@Master, FileId, Path),
    directory_listing(@Master, FileId, DirListing);

// "ls" for nonexistent path => error
response(@Source, RequestId, false, null) :-
    request(@Master, RequestId, Source, "Ls", Path),
    notin fqpath(@Master, _, Path);
```

Comparison with Hadoop

Competitive performance (~20%)

	Lines of Java	Lines of Overlog
HDFS	~21,700	0
BOOM-FS	1,431	469

New Features:

1. Hot Standby for FS master nodes using Paxos
2. Partitioned FS master nodes for scalability
   – ~1 day!
3. Monitoring, tracing, and invariant checking

Lessons from BOOM Analytics

- Overall, Overlog was a good fit for the task
  - Concise programs for real features, easy evolution
- Data-centric design: language-independent
  - Replication, partitioning, monitoring all involve data management
  - Node-local invariants are "cross-cutting" queries
    - Specification *is* enforcement
- Policy vs. mechanism ⇔ Datalog vs. Java

Challenges from BOOM Analytics

- Poor perf, cryptic syntax, little/no tool support
  - Easy to fix!
- Many bugs related to updating state
  - Ambiguous semantics (in Overlog)
- We avoided distributed queries
  - "The global database is a lie!"
  - Hand-coding protocols vs. stating distributed invariants

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Dedalus

- Dedalus: a theoretical foundation for Bloom
- In Overlog, the Hard Stuff happens **between** time steps
  - State update
  - Asynchronous messaging
- Can we talk about the Hard Stuff with logic?

State Update

- Updates in Overlog: **ugly**, “outside” of logic
- Difficult to express common patterns
  - Queues, sequencing
- Order doesn’t matter ... except when it does!

```
counter(@A, Val + 1) :- counter(@A, Val),
                        event(@A, _);
```

Asynchronous Messaging

- Overlog "@" notation describes **space**
- Logical interpretation unclear:

```
p(@A, B) :- q(@B, A);
```

- Upon reflection, ***time*** is more fundamental
  - Model failure with arbitrary delay
- Discard illusion of global DB

Dedalus: Datalog in Time

(1) Deductive rule: (Pure Datalog)

```
p(A, B) :- q(A, B);
```

(2) Inductive rule: (Constraint across "next" timestep)

```
p(A, B)@next :- q(A, B);
```

(3) Async rule: (Constraint across arbitrary timesteps)

```
p(A, B)@async:- q(A, B);
```

Dedalus: Datalog in Time

(1) Deductive rule: (Pure Datalog)

All terms in body have same time

```
p(A, B, S) :- q(A, B, T), T = S;
```

(2) Inductive rule: (Constraint across “next” timestep)

```
p(A, B, S) :- q(A, B, T), successor(T, S);
```

(3) Async rule: (Constraint across arbitrary timesteps)

```
p(A, B, S) :- q(A, B, T), time(S),
                         choose((A, B, T), (S));
```

State Update in Dedalus

p (A, B)@next :- p (A, B), notin p_neg(A, B);

p (1, 2)@101;

p (1, 3)@102;

p_neg(1, 2)@300;

Time	p(1, 2)	p(1, 3)	p_neg(1, 2)
101			
102			
…			
300			
301			

Counters in Dedalus

```
counter(A, Val + 1)@next :-
    counter(A, Val),
    event(A, _);

counter(A, Val)@next :-
   counter(A, Val),
   notin event(A, _);
```

Asynchrony in Dedalus

Unreliable Broadcast:

```
sbcast(#Target, Sender, Message)@async :-
    new_message(#Sender, Message),
    members(#Sender, Target);
```

- More satisfactory logical interpretation
- Can build Lamport clocks, reliable broadcast, etc.
- What about “space”?
    - Space is the unit of atomic deduction w/o partial failure

Asynchrony in Dedalus

Unreliable Broadcast:

Project sender's local time

```
sbcast(#Target, Sender, N, Message)@async :-
   new_message(#Sender, Message)@N,
   members(#Sender, Target);
```

- More satisfactory logical interpretation
- Can build Lamport clocks, reliable broadcast, etc.
- What about "space"?
  - Space is the unit of atomic deduction w/o partial failure

Dedalus Summary

- Logical, model-theoretic semantics for two key features of distributed systems
  1. Mutable state
  2. Asynchronous communication
- All facts are transient
  - Persistence and state update are explicit
- Initial correctness checks
  1. Temporal stratifiability ("modular stratification in time")
  2. Temporal safety ("eventual quiescence")

Directions: Bloom

1. Bloom: Logic for Joe the Programmer
   – Expose sets, map/reduce, and callbacks?
   – Translation to Dedalus
2. Verification of Dedalus programs
3. Network-oriented optimization
4. Finding the right abstractions for Distributed Computing
   – Hand-coding protocols vs. stating distributed invariants
5. Parallelism and monotonicity?

Questions?

Thank you! http://declarativity.net

Initial Publications:

- *BOOM Analytics*: EuroSys'10, Alvaro et al.
- *Paxos in Overlog*: NetDB'09, Alvaro et al.
- *Dedalus*: UCB TR #2009-173, Alvaro et al.

Temporal Stratifiability

Reduction to Datalog not syntactically stratifiable:

```
p(X)@next :- p(X), notin p_neg(X);
p_neg(X) :- event(X, _), p(X);
```