Declarative Networking

Mothy

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Off the top of my head…

- Running packet networks remains a complex and difficult problem.
- Despite ~25 years of research, no abstractions have emerged to modularize the problem.
- I find this astonishing. Can someone correct me?

It's not all been wasted…

- Lots of measurement
  - ⇒ lots and lots of data now
- Understand "network level" well
  - TCP, BGP, Malware, etc.
- Plenty of control mechanisms
  - DCAN, RCP, 4D, etc., etc.

- Hypothesis: for IP at least, we as researchers already understand this well enough to abstract and uplevel.
- Can we just move on?

Mental exercise

- For a moment, try to forget everything you know about BGP, OSPF, IS-IS, DVMRP, etc., etc.
- Take a deep breath or two.
- Doesn't that feel good?

A different abstraction

- The set of routing tables in a network represents a *distributed data structure*
- The data structure is characterized by a set of ideal *properties* which define the network
  - Think in terms of structure, not protocol
- *Routing* is the process of maintaining these properties in the face of changing ground facts
  - Failures, topology changes, load, policy…

Routing and Query Processing

- In database terms, the routing table is a *view* over changing network conditions and state
- Maintaining it is the domain of distributed continuous query processing

Distributed Continuous Query Processing

- Relatively new and active field
  - SDIMS, Mercury, IrisLog, Sophia, etc., in particular PIER
  - $\Rightarrow$ May not have all the answers yet
- But brings a wealth of experience and knowledge from database systems
  - Relational, deductive, stream processing, etc.

Goal: a constrained declarative language for network specification

- Higher-level view of routing properties
  - More than simply a configuration language
- Modular decomposition of function
- Static analysis for:
  - Optimization techniques
  - Safety checking
- Dynamic optimization
  - C.f. eddies, etc.

Other advantages

- Can incorporate other knowledge into routing policies
  - C.f. Jennifer's examples, and beyond
  - E.g. Physical network knowledge
- Naturally integrates *discovery*
  - If you buy Paul's argument
- Also provides an abstraction point for such information
  - Knowledge itself doesn't need to be exposed.

What are we doing, then?

- Express network properties in *DataLog*
  - Preliminary to better languages
- Execute specifications to maintain routing and discovery
- Two directions / implementations:
  - IP Routing (SIGCOMM 2005)
  - Overlays (under submission)

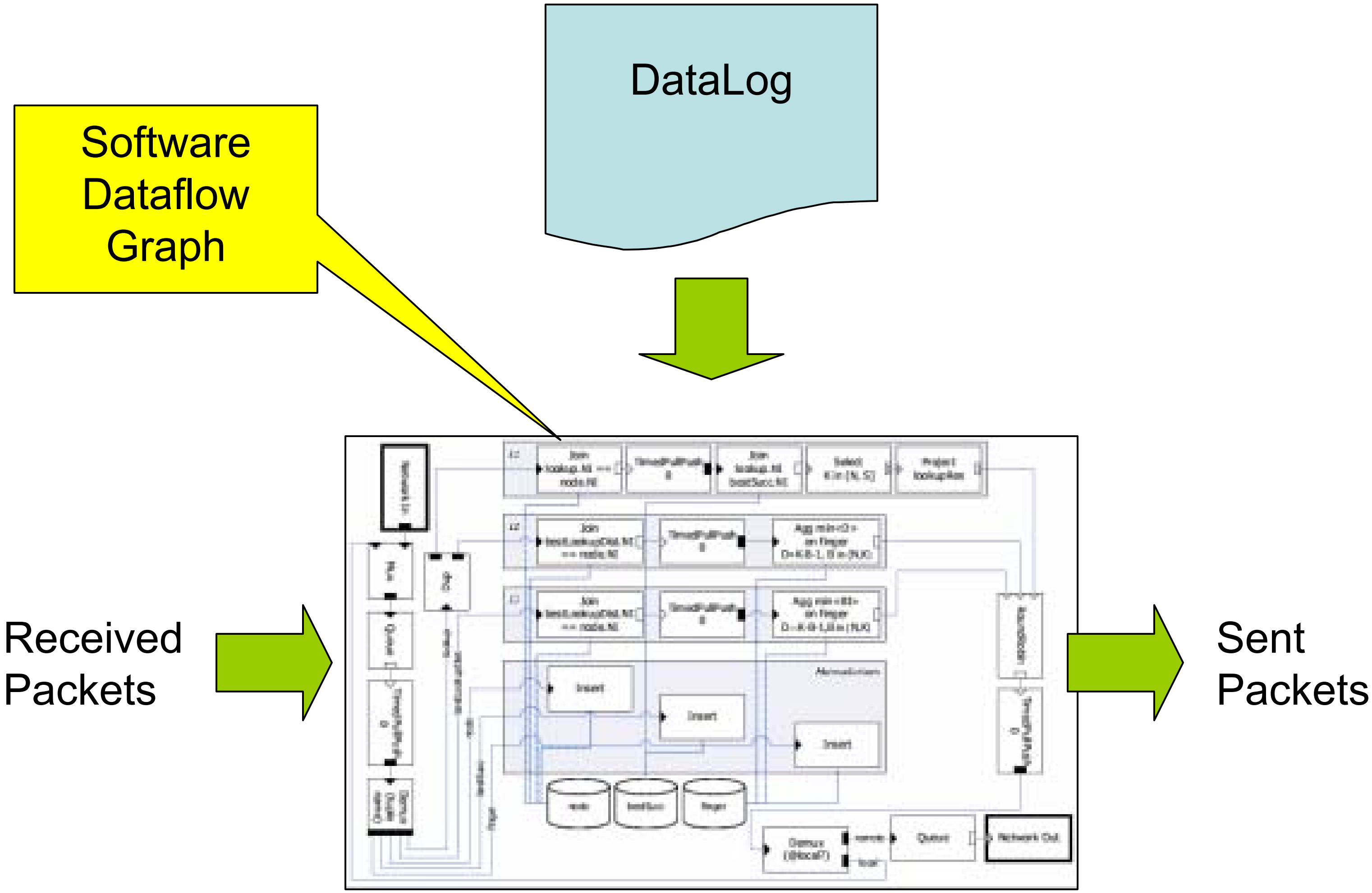
Why overlays?

- Overlays in a very *broad* sense
  - Any application-level routing system
  - Email servers, multicast, CDNs, DHTs, etc.
- Ideal test case
  - Clearly deployable short-term
  - Defers interoperability issues
- The overlay design space is wide
  - $\Rightarrow$ ensures we cover the bases
- Testbed for wider applicability

A Declarative Overlay Engine: "P2"

- Everything is a declarative query
  - Overlay construction, maintenance, routing, monitoring
- Queries compiled to software dataflow graph and directly executed
- System written from scratch (C++)
  - Deployable (PlanetLab, Emulab)
  - Already has reasonable performance for deployed overlays

P2



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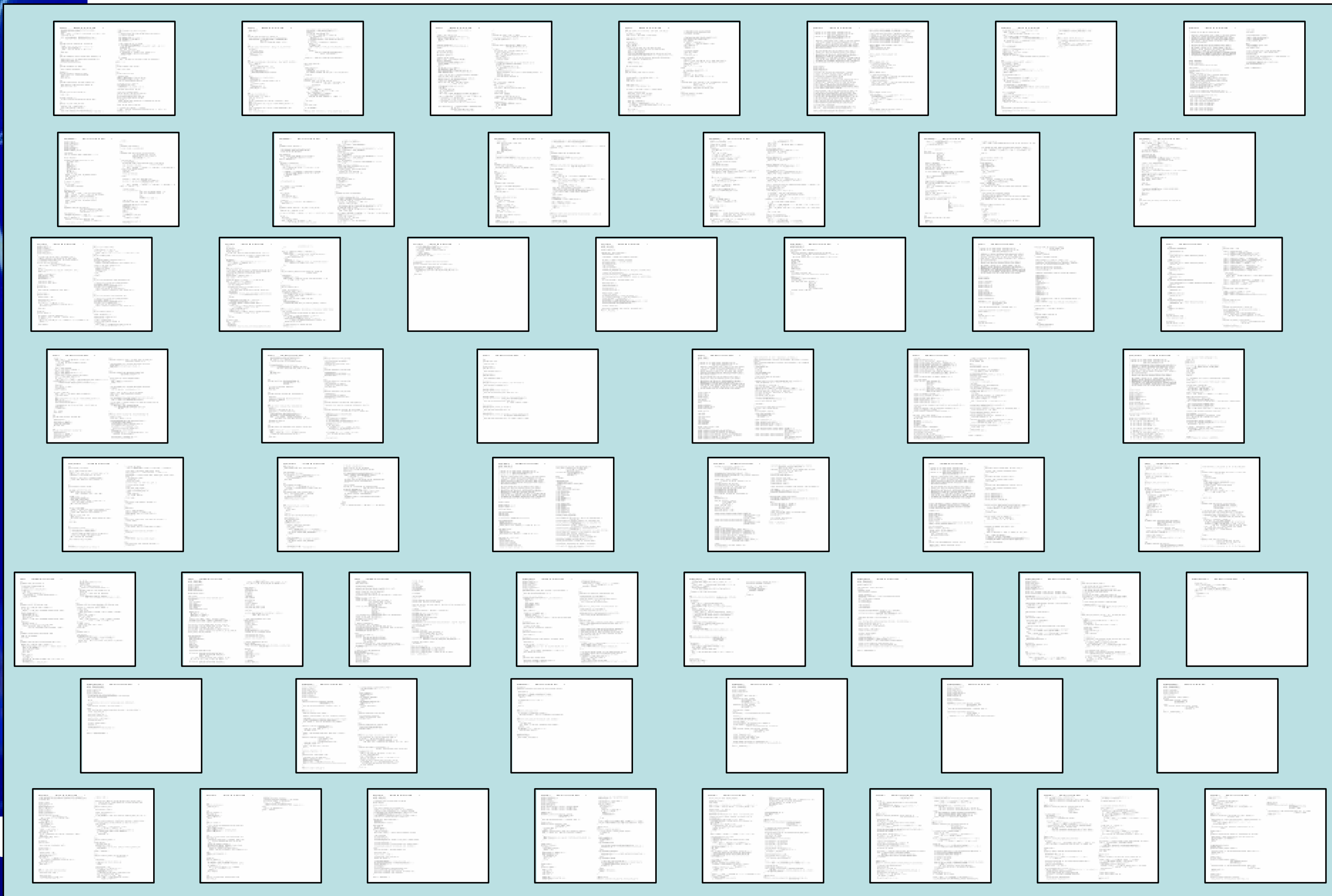
Example: Chord in 33 rules

```
chord.plg        Sun Apr 10 23:43:49 2005        1

/*
 * 1.1 Chord
 * ---------
 */

/* The base tuples */
materialise(node, infinity, 1).
materialise(bestSucc, tSucc * 2, 1).
materialise(finger, tFix * 2, 160).
materialise(succ, tSucc * 2, 16).
materialise(pred, infinity, 1).
materialize(join, tJoin, 5).
materialize(landmark, infinity, 5).
materialize(stabilize, tStabilizeWait, 5).
materialize(pingNode, tPingSoftState, infinity).

/** Lookups |||3||| */
rule L1 lookupResults@R(R,K,S,SI,E) :- node@NI(NI,N), lookup@NI(NI,K,R,E),
        bestSucc@NI(NI,S,SI), K in (N,S].
rule L2 bestLookupDist@NI(NI,K,R,E,min<D>) :- lookup@NI(NI,K,R,E),
        finger@NI(NI,I,B,BI), node@NI(NI,N), B in (N,K), D=K-B-1.
rule L3 lookup@BI(min<BI>,K,R,E) :- node@NI(NI, N),
        bestLookupDist@NI(NI,K,R,E,D), B in (N,K).
        finger@NI(NI,I,B,BI), D=K-B-1.

/* Neighbor Selection |||3||| */
rule SU1 bestSuccDist@NI(NI,min<D>) :- node@NI(NI,N), succ@NI(NI,S,SI),
        D=S-N-1.
rule SU2 bestSucc@NI(NI,S,SI) :- succ@NI(NI,S,SI),
        bestSuccDist@NI(NI,D), node@NI(NI,N), D=S-N-1.
rule SU3 finger@NI(NI,0,S,SI) :-
        bestSuccessor@NI(NI,S,SI).

/* Successor eviction |||4||| */
rule SR1 succCount(NI,count<>) :- succ(NI,S,SI).
rule SR2 evictSucc@NI(NI) :- succCount@NI(NI,C), C >
        succSize.
rule SR3 maxSuccDist@NI(NI,max<D>) :- succ@NI(NI,S,SI),
        node@NI(NI,N), D = f_dist(N,S)-1, evictSucc@NI(NI).
rule SR4 delete@NI<succ(NI,S,SI)> :- succ@NI(NI,S,SI),
        maxSuccDist@NI(NI,D), D=f_dist(N,S)-1.

/* Finger fixing |||3||| */
rule F1 fFix@NI(NI,E,I) :- periodic@NI(NI,E,t_Fix), I in [0, fNum),
        f_coinFlip(fFixProb).
rule F2 lookup@NI(NI,K,NI,E) :- fFix@NI(NI,E,I), node(NI,N), K = N + 1
        << I.
rule F3 finger@NI(NI,I,B,BI) :- fFix@NI(NI,E,I),
        lookupRes@NI(NI,K,B,BI,E), K in (N + 1<<I, N), node@NI(NI,N).

/* Churn Handling |||5||| */
rule J1 pred@NI(NI,null,"").
rule J2 joinReq@LI(LI,N,NI,E) :- join@NI(NI,E), node@NI(NI,N),
        landmark@NI(NI,LI), LI != "".
rule J3 succ@NI(NI,N,NI) :- landmark@NI(NI,LI), node@NI(NI,N),
        join@NI(NI,E), LI = "".
rule J4 lookup@LI(LI,N,NI,E) :- joinReq@LI(LI,N,NI,E).
rule J5 succ@NI(NI,S,SI) :- join@NI(NI,E), lookupRes@NI(NI,K,S,SI,E).

/* Stabilization |||8||| */
rule S0 stabilize@NI(NI, E) :- periodic@NI(NI, E, t_stab).
rule S1 stabilizeReq@SI(SI,NI,E) :- stabilize@NI(NI,E),
        bestSucc@NI(NI,S,SI).
rule S2 sendPred@PI1(PI1,P,PI,E) :- stabilizeReq@NI(NI,PI1,E),
        pred@NI(NI,P,PI), PI != "-".
rule S3 succ@NI(NI,P,PI) :- node(NI,N), sendPred@NI(NI,P,PI,E),
        bestSucc@NI(NI,S,SI), P in (N,S), stabilize@NI(NI,E).
rule S4 sendSucc@SI(SI,NI) :- stabilize@NI(NI, E),
        succ@NI(NI,S,SI).
rule S5 succ@PI(PI,S,SI) :- sendSucc@NI(NI,PI), succ@NI(NI,S,SI).
rule S6 notifyPred@SI(SI,N,NI) :- stabilize@NI(NI, E), node@NI(NI,N),
        successor@NI(NI,S,SI).
rule S7 pred@NI(NI,P,PI) :- node@NI(NI,N), notifyPred@NI(NI,P,PI),
        pred@NI(NI,P1,PI1), ((PI1 == "") || (P in (P1, N))).

/** Connectivity Monitoring */
rule C1 pingReq@PI(PI, NI, E, TS) :- periodic@NI(NI, E, tPing),
        pingNode@NI(NI, PI), TS = f_currentTime().
rule C2 pingResp@RI(RI, NI, E, TS) :- pingReq@NI(NI, RI, E, TS).
rule C3 latency@NI(NI, PI, L) :- pingReply@NI(NI, PI, E, TS),
        pingReq@NI(NI, PI, E, TS1), TS2 = f_currentTime(), L = TS2 -
        TS1.

rule CS1 pingNode@NI(NI,SI) :- succ@NI(NI,S,SI).
rule CS2 succ@NI(NI, S, SI) :- succ@NI(NI, S, SI), latency@NI(NI, SI,
        L).

rule CF1 pingNode@NI(NI,PI) :- finger@NI(NI,I,B,BI).
rule CF2 finger@NI(NI, I, B, BI) :- finger@NI(NI, I, B, BI),
        latency@NI(NI, BI, L).
```

Comparison: MIT Chord in C++



Conclusion

- An abstraction and infrastructure for radically rethinking networking
  - One possibility: System R for networks
- Where does the network end and the application begin?
  - E.g. can run queries to monitor the network at the endpoints
  - Integrate resource discovery, management, routing
  - Chance to reshuffle the networking deck

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Thanks.