Building diagnosable distributed systems

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ICSI – Security Crystal Ball

…and how that's going to solve all of our (security) problems

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Why distributed systems are hard

In every application, organizing distributed resources has unique needs

- Low latency, high bandwidth, high reliability, tolerance to churn, anonymity, long-term preservation, undeniable transactions, …

So, for every application one must

- Figure out right properties
- Get the algorithms/protocols
- Implement them
- Tune them
- Test them
- Debug them
- Repeat

Why distributed systems are hard (among other things)

In every application, organizing distributed resources has unique needs

- Low latency, high bandwidth, high reliability, tolerance to churn, anonymity, long-term preservation, undeniable transactions, …

So, for every application one must

• Figure out right properties	☞ No global view
• Get the algorithms/protocols	☞ Bad algorithm choice
• Implement them	☞ Incorrect implementation
• Tune them	☞ Psychotic timeouts
• Test them	☞ Partial failures
• Debug them	☞ Biased introspection
• Repeat	☞ Homicidal boredom

Diagnostic vs. Diagnosable Systems

Diagnostic is good

- Complex query processing
- Probes into distributed system exporting data to be queried
- Nice properties
  - Privacy, efficiency, timeliness, consistency, accuracy, verifiability

Diagnosable is even better

- Information flow can be observed
- Control flow can be observed
- Observations can be related to system specification
  - no need for “translation”

If you are really lucky, you can get both

Strawman Design: P2 (Intel, UCB, Rice, MPI)

Intended for user-level distributed system design, implementation, monitoring

Specify high-level system properties

- Abstract topology
- Transport properties

Currently: in a variant of Datalog

- Looks like event-condition-action rules
- Location specifiers place conditions in space
- Rendezvous happens under the covers

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```
response@Req(Key, SAddr1) :-
   lookup@NAddr(Req, Key),
   node@NAddr(NodeID),
   succ@Naddr(NextID, SAddr),
   succ@SAddr(NextNextID, SAddr1),
   Key in (NodeID, Succ].
```

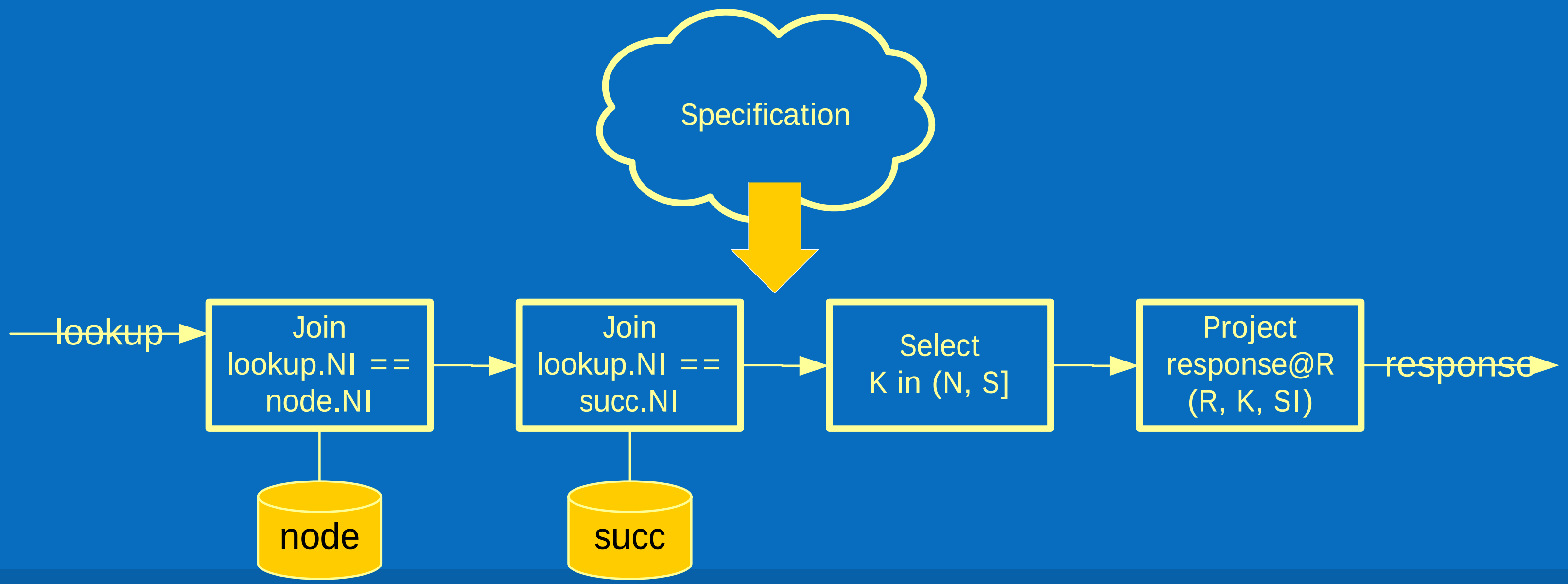
In English:

- Return a response to Req
- When node NAddr receives lookup for key Key
- And that key lies between NAddr's identifier and that of its successor's successor

Strawman Design: P2 Specification to Implementation

Automatically compile specification into a dataflow graph

- Elements are little-functionality operators
  - Filters, multiplexers, loads, stores
- Elements are interlinked with asynchronous data flows
  - Data unit: a typed, flat tuple
- Reversible optimizations happen below



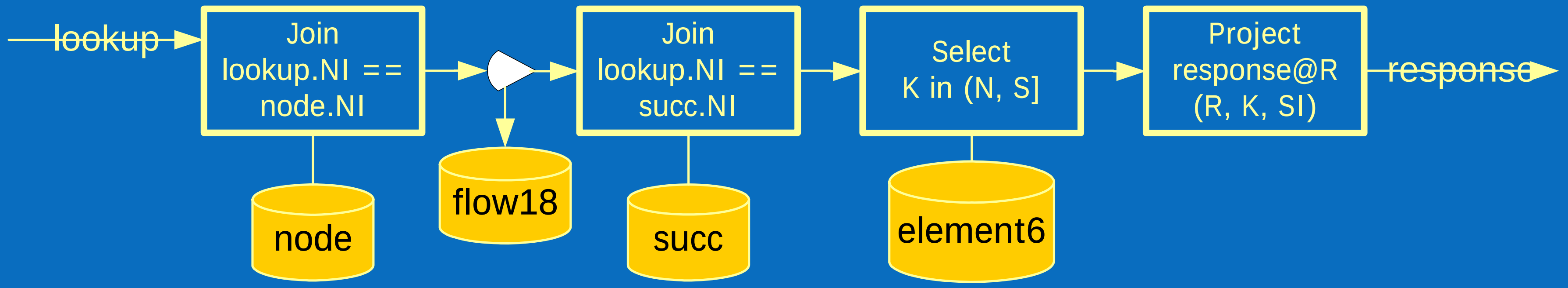
Strawman Design: P2 Diagnosis

Flows are observable

- Treat them as any other data stream, store, query them…

Element state transitions are observable

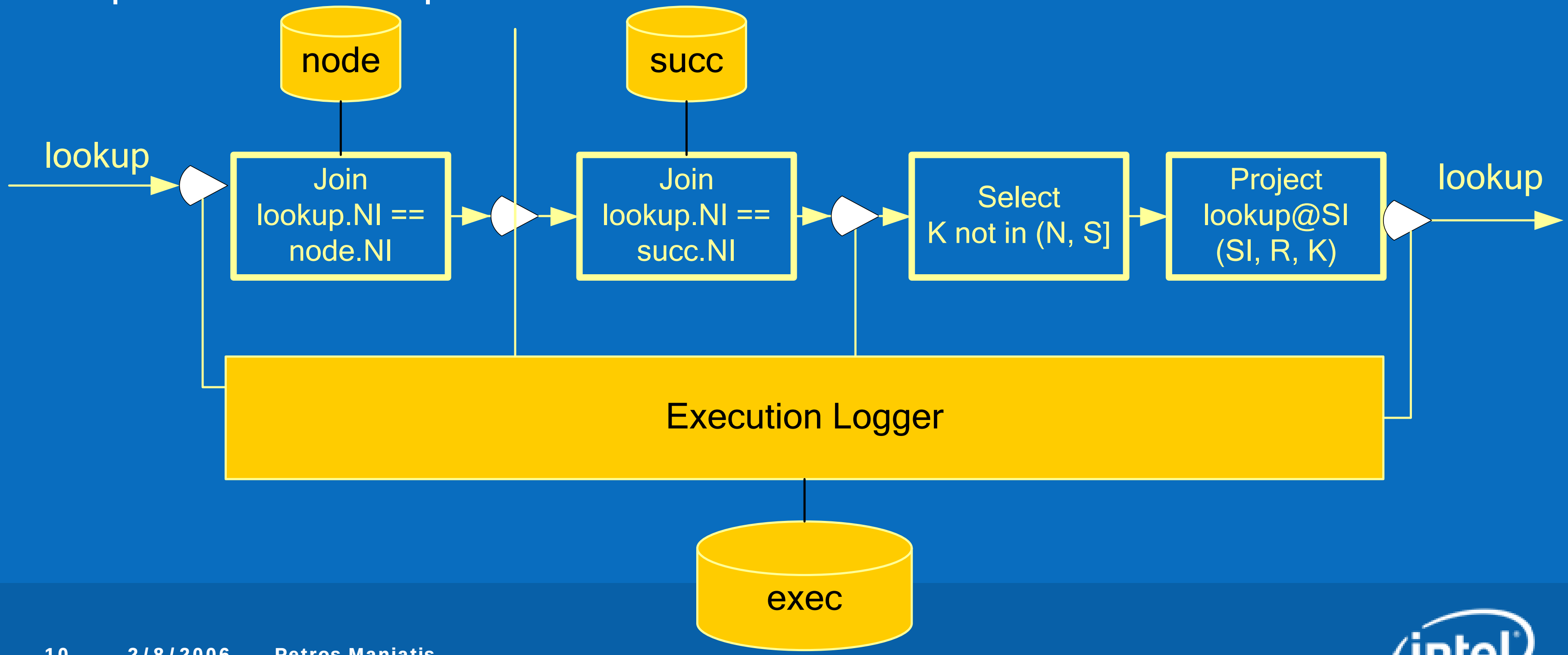
- Similarly, store them, query them, export them…



Strawman Design: P2 Execution Tracing

Execution is observable

- Whenever a rule creates an output, I can log the inputs that caused that output
- Generate a causal stream at the granularity of the user's specification steps



What we know we can do (e.g., in overlays)

Monitoring invariants: a distributed watchpoint

- “A node’s in-degree is greater than k”
- “Routing is inconsistent”
- “A node oscillates into and out of a neighborhood’s routing tables”

Execution tracing at “pseudo-code” granularity: logical stepping

- Obtain the causality graph of a failed lookup (what steps led to failure)
- Find failed lookups with state oscillations in its history (filter failure cause)
- Install additional sensors where state oscillations usually cause lookup failure
- Mining of causality graph on-line

Complex programmatic system views

- Run a consistent snapshot on the state of the system
- Query the consistent snapshot on stable properties
- Take system checkpoints

Opportunities

What we'd love to be able to do but don't quite know exactly how yet

Small set of basic components

- Relational operators, flow operators, network operators
- Should be able to formally validate them
- Then compose to statically validate entire graph (termination, information flow, etc.)

Verifiable dataflow graph execution

- Attest all dataflow elements in isolation
- Attest resulting dataflow graph

Undeniable causality graphs

- Tamper-evident logs per dataflow element
- (Automatically) composable proofs of compliant execution of dataflow graph

Smaller combinatorial problems:

- Chord overlay: ~10000 individual lines of code in C++
- Compare that to our P2Chord: ~300 elements, ~12 reusable types, + engine

What we'd love to be able to do but don't quite know exactly how yet

What might be a useful checked invariant?

- Known protocol weakness we don't know how to fix
- Design a distributed query checking for it
- When it triggers, abort, work less slowly, notify authorities, give random answer, …

Graph rewrites that preserve specific properties

- Information declassification (look at Saberfeld et al)
- Routing path decorrelation

Who cares about verifiable, user-level distributed applications?

- Monitoring within disparate organizations

Who cares about undeniable, user-level distributed applications?

- Same, when liability is involved (e.g., anti-framing)

What do we have here?

Constrained programming/execution environment

- Typed information flow
- Very modular design
- Small set of functional modules can build large set of combinations
- Only reversible optimizations allowed

But we're nowhere near solving the malicious code understanding prob

- Can we afford to take the performance hit?
- Fairly coarse granularity
- Can you write a general-purpose Distributed FS on this? Hmm…

Thesis: Defining a usable (if not *complete*) programming paradigm that allows "effortless" due diligence might improve the situation

Thank You!

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