Persistent Functional Languages: towards Functional Relational Databases

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Persistence

Data that outlives the execution of a program:

- Websites
- Information Systems
- Operating Systems
- Version Control Systems
- ...

Serialization to files on disk

Ad-hoc queries?

Schema transformations?

Concurrent operations?

...

Database Management Systems

Ad-hoc queries

Schema transformations

Concurrent operations

Share data between programs

Very large states

Query Optimization

Parallelism

Data Integrity

Enforce Constraints

Replication

…

Difficulties using DBMS’s

Forces the program into the database model:

- Data model mapping
- Type mapping

Verification is difficult:

- Type checking
- Testing
- Formal verification

Weak Points of DBMS’s

Largely fixed function, e.g.:

- Fixed data model
- Fixed data types
- Fixed index types

DBMS’s can’t really optimize database *updates*

- Database program execution is not under the control of the DBMS.

Persistent Languages

Ideal solution: Integrate a programming language with the features of a DBMS.

Not much success so far:

- Incompatible semantic models
- Optimization is a problem

Functional Persistent Languages

XQuery shows that functional languages are:

- Compatible with databases.
- Optimizable and parallelizable.

Using functional languages for the *updating* of databases has not really been explored.

Transactions

A transaction is a collection of operations, which execution satisfies the ACID properties:

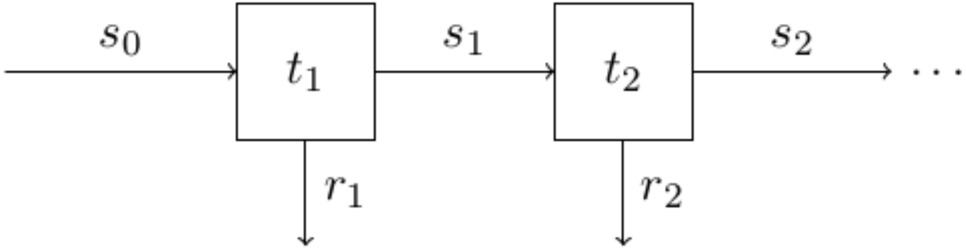
- Atomicity
- Consistency
- Isolation
- Durability

Functional Transactions

```
type Transaction :: DB -> (DB, Result)
```

Functional Transaction Processing

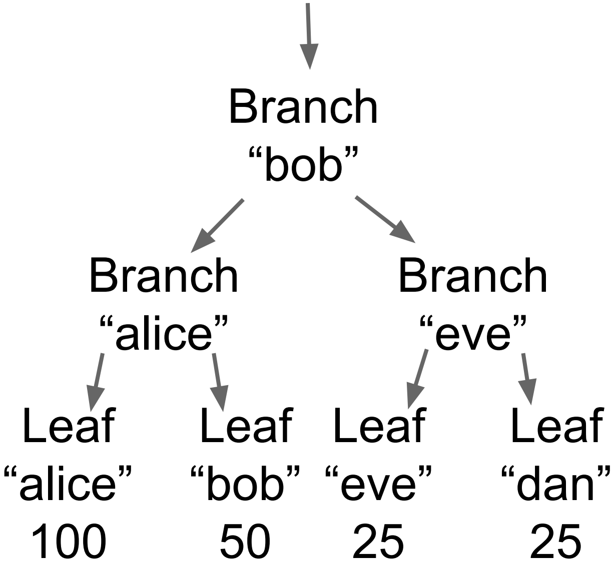
```
tm :: DB -> [Transaction] -> [Result]
tm s (tx:txs) =
   let (ns, r) = tx(s) in
      r : (tm ns txs)
```



Functional Transaction Processing

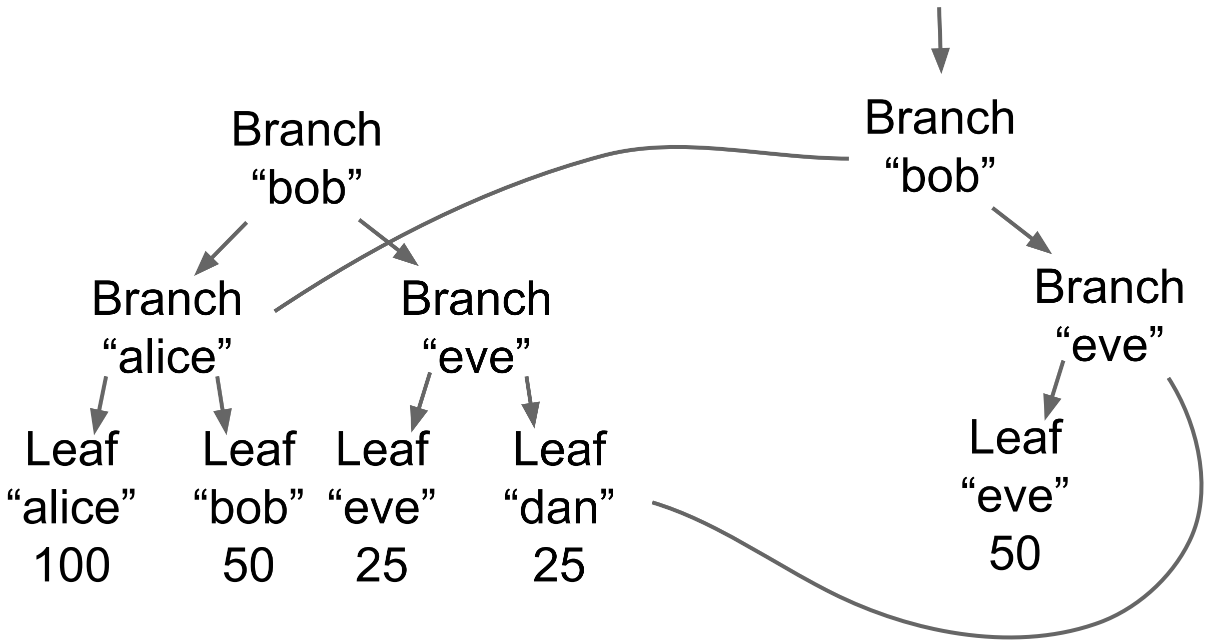
```
data Maybe a = Just a | Nothing

incr s = (s+1, Nothing)
read s = (s, Just s)

> tm 0 [incr, incr, read] [Nothing,
Nothing,Just 2]
```

Functional States




```
data Tree k v
  = Branch k (Tree k v) (Tree k v)
  | Leaf k v
```

Functional Updates



Persistence

Simple persistence model:

- Journal transaction before executing.
- Recover state from latest snapshot by replaying journaled transactions from the initial state.
- Snapshot the state to clear the journal.

Constraints and Aborts

Enforce a constraint `check : DB -> Bool` over the state:

```
let (ns, r) = tx(s) in
  if check(ns) then (ns, r) else (s, Error)
```

Abort by returning the original state.

Transactions

This model satisfied the ACID properties:

- Atomic
- Consistent
- Isolated
- Durable

But how do we execute transactions in parallel?

Concurrent Transaction Execution

Idea: Evaluate states lazily.

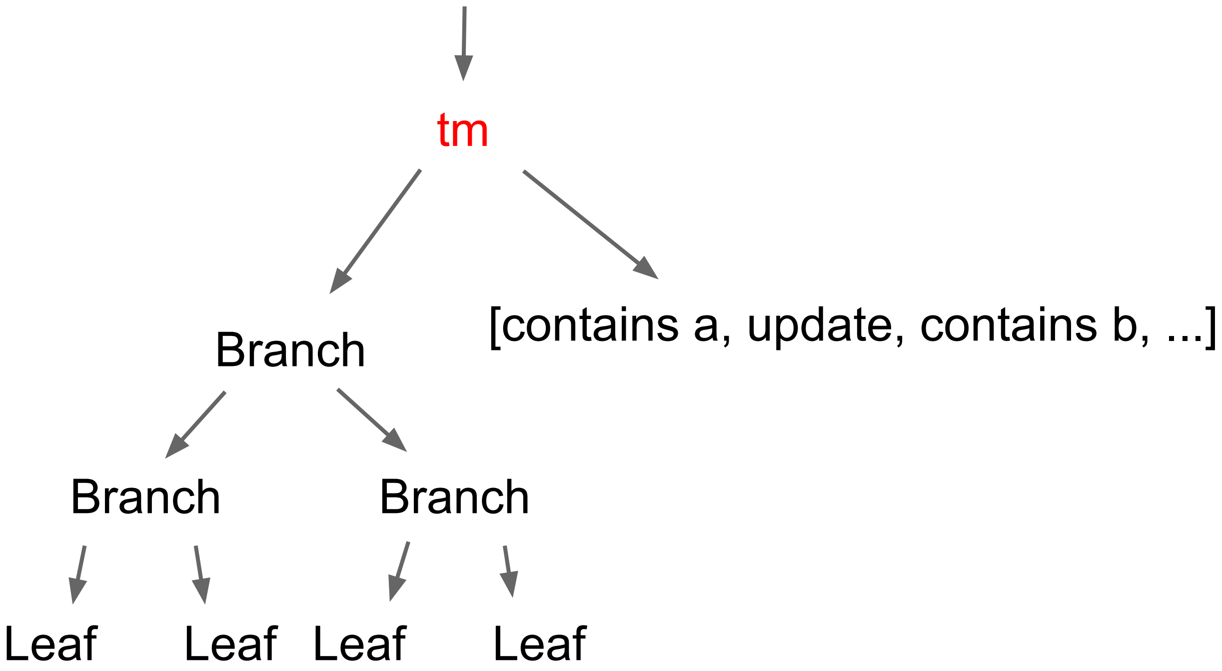
```
update s = (map f s, Nothing)
contains k s = (s, contains k s)
```

```
tm (Branch ...) [contains a, update,
contains b, ...]
```

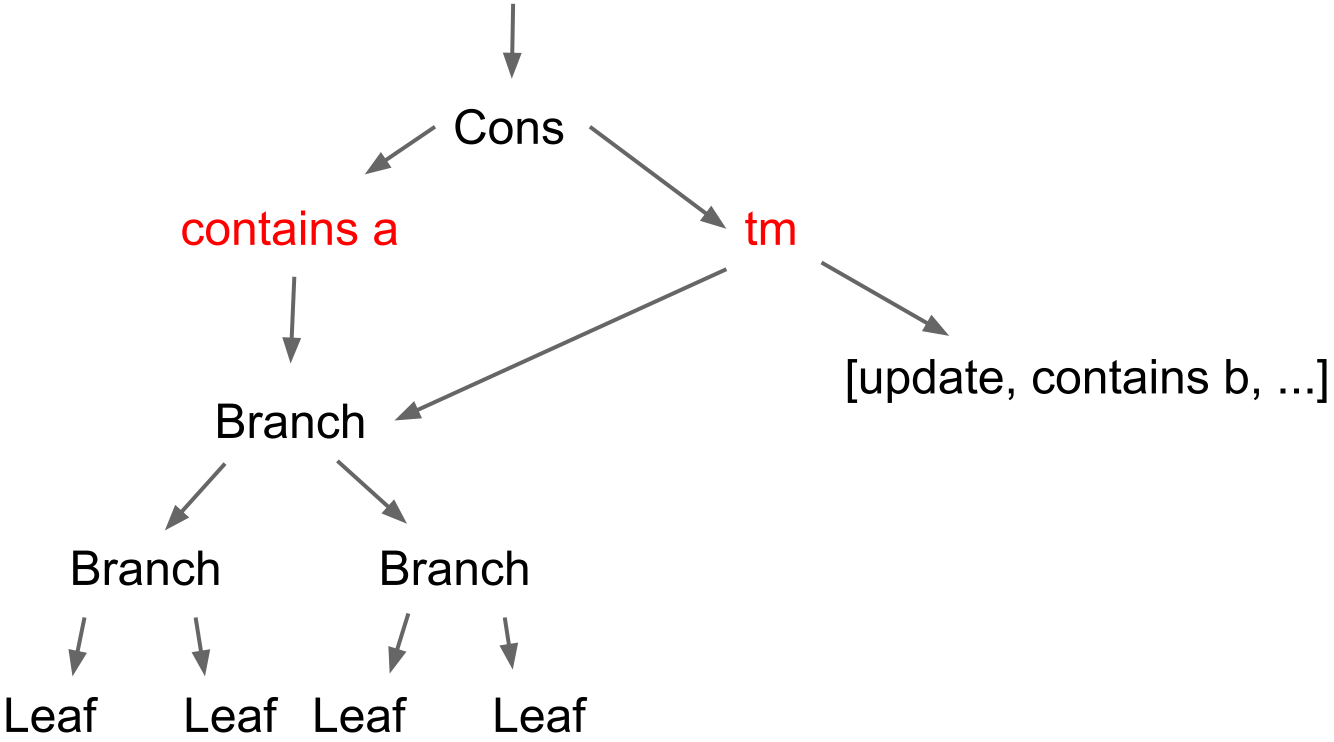
Concurrent Transaction Processing

tm (Branch ...) [contains a, update, contains b, ...]

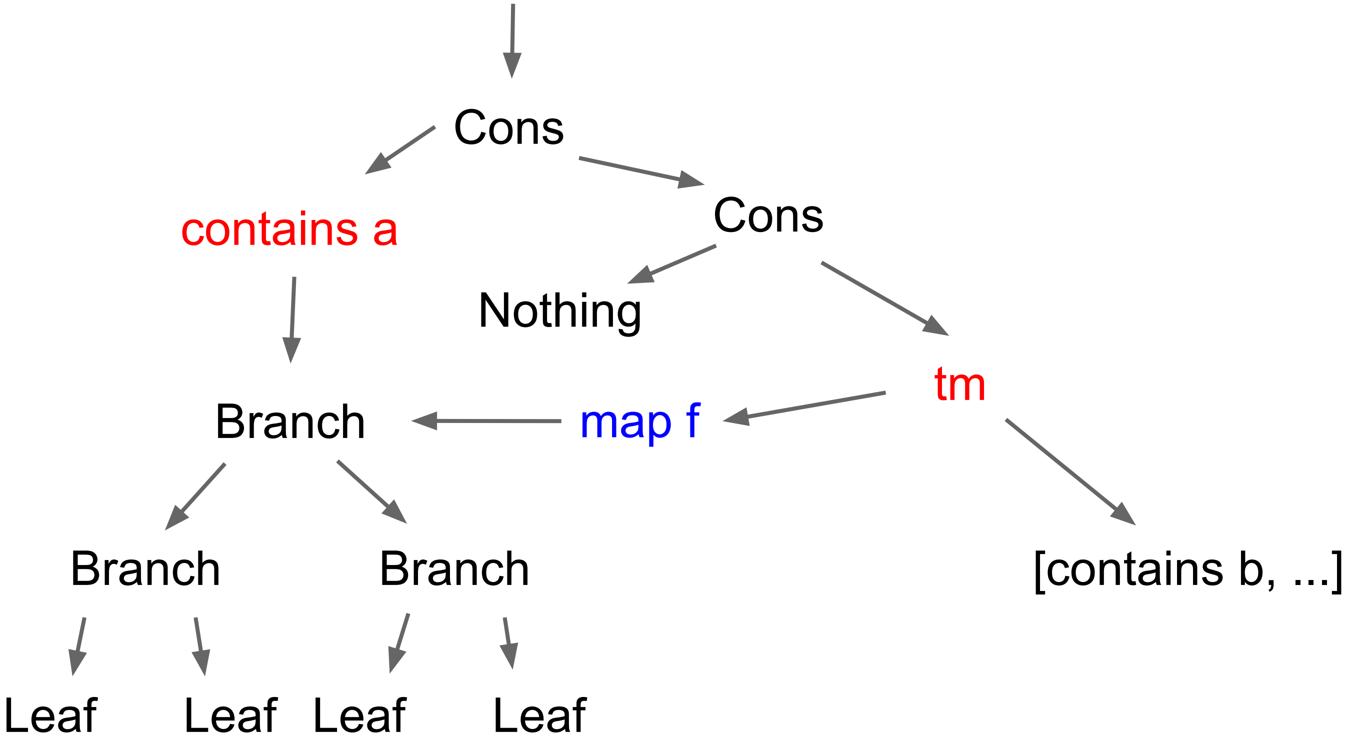
Concurrent Transaction Processing



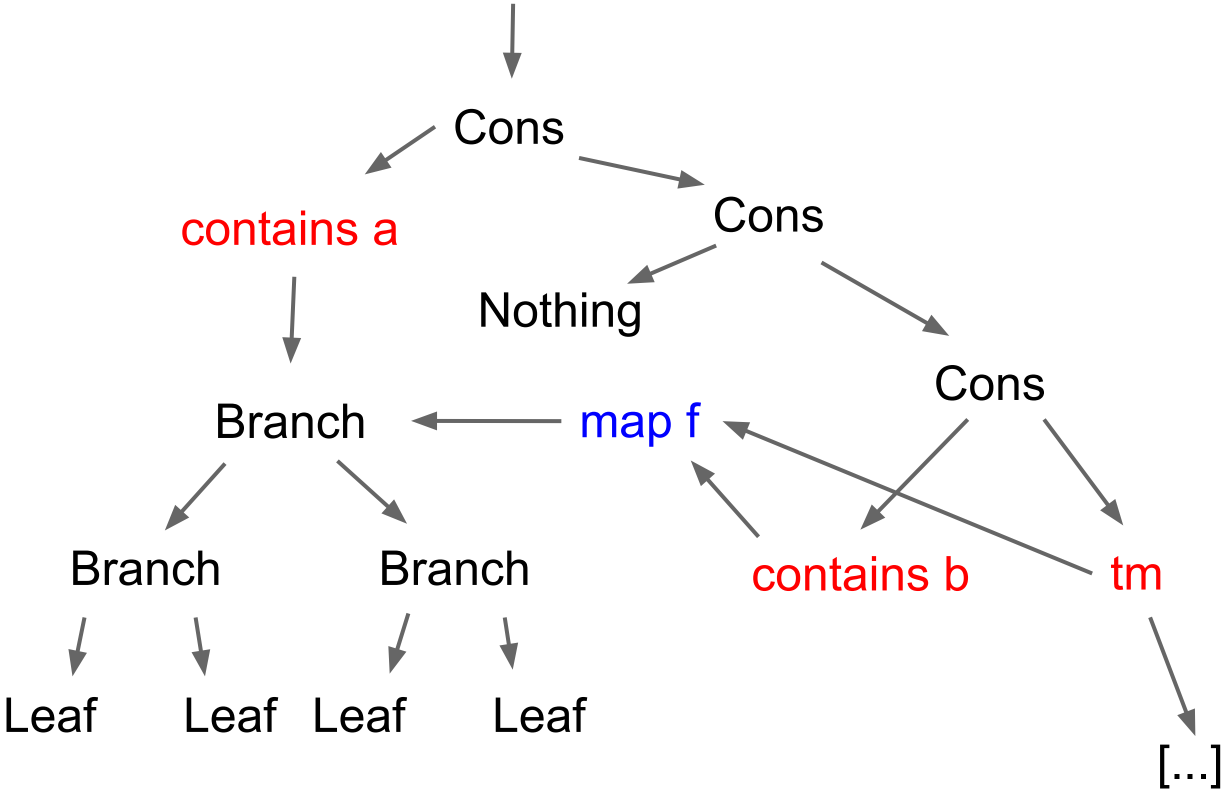
Concurrent Transaction Processing



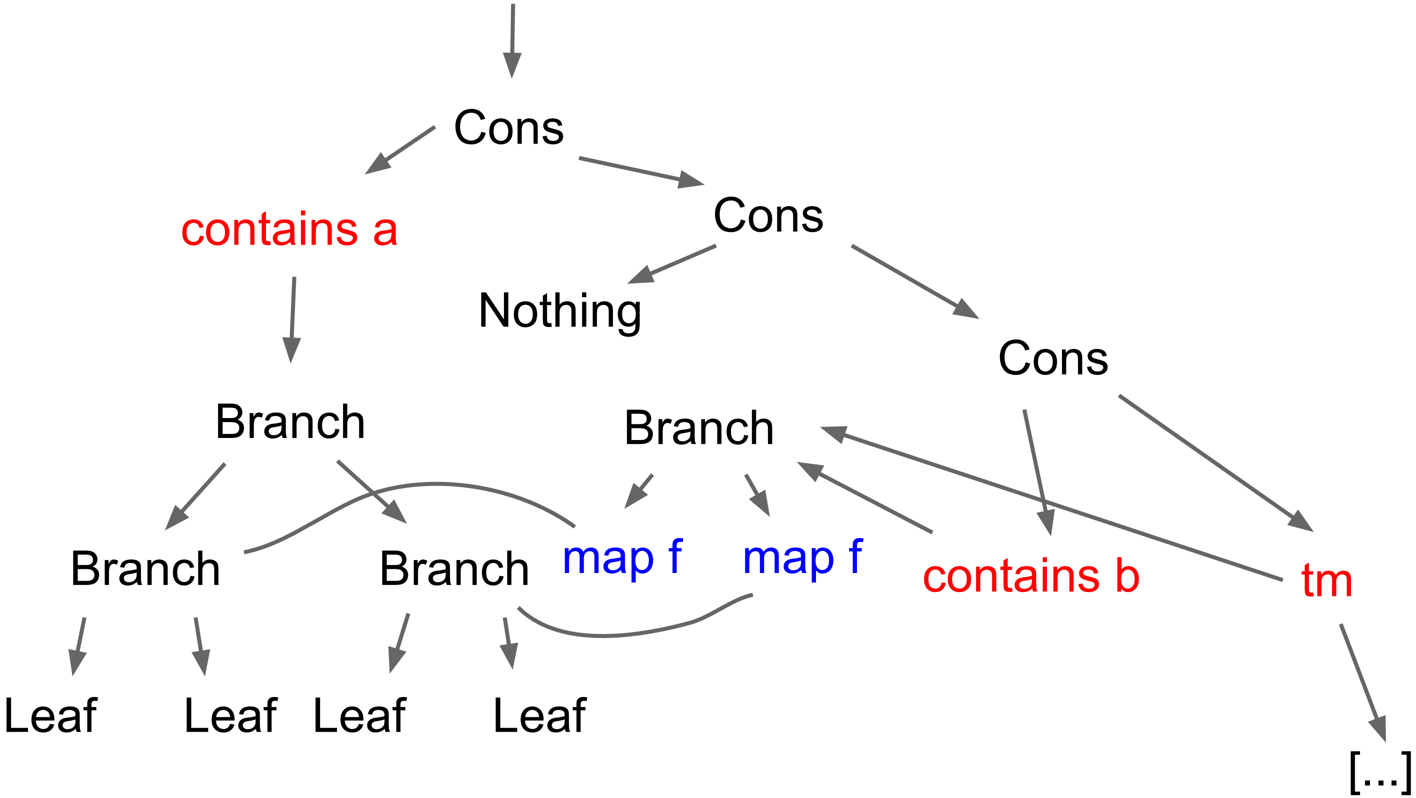
Concurrent Transaction Processing



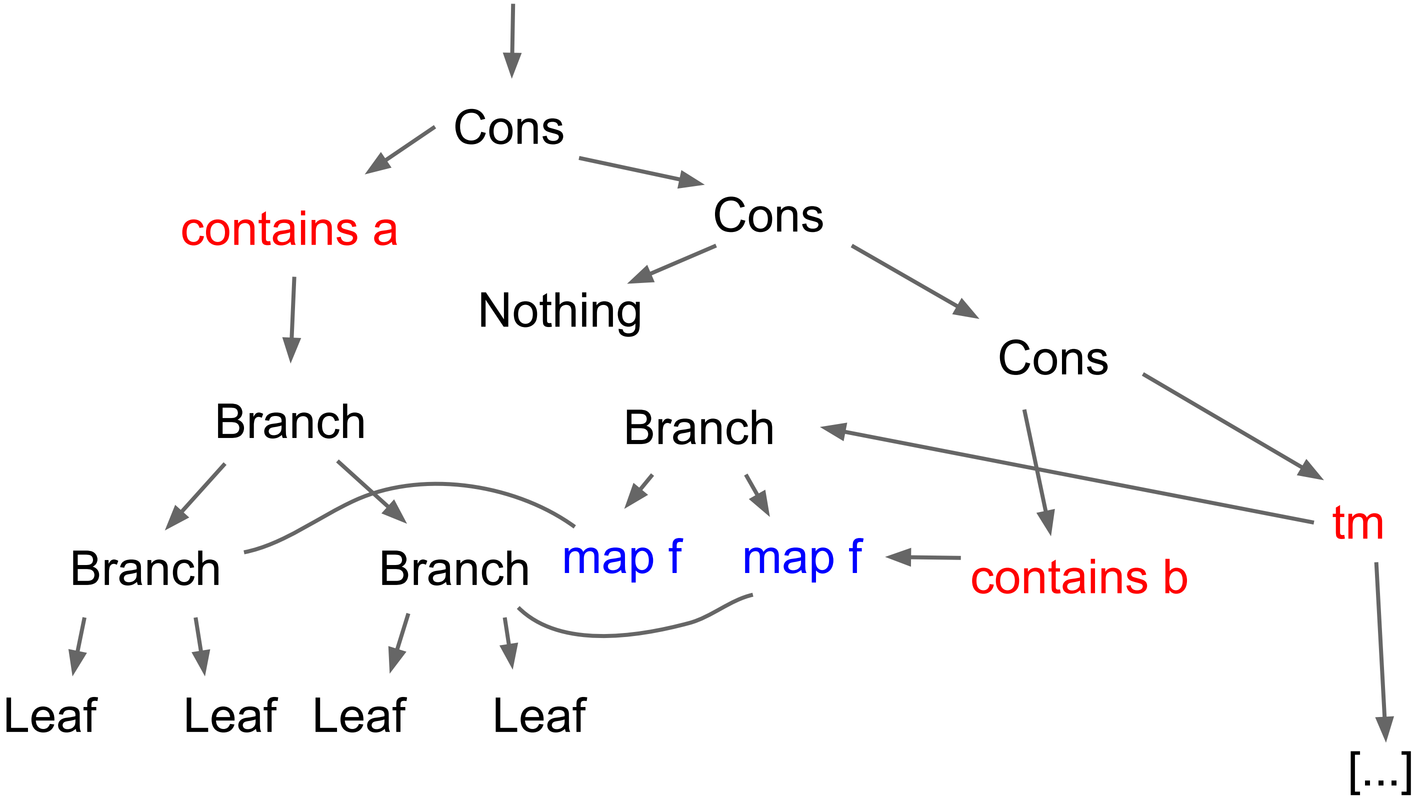
Concurrent Transaction Processing



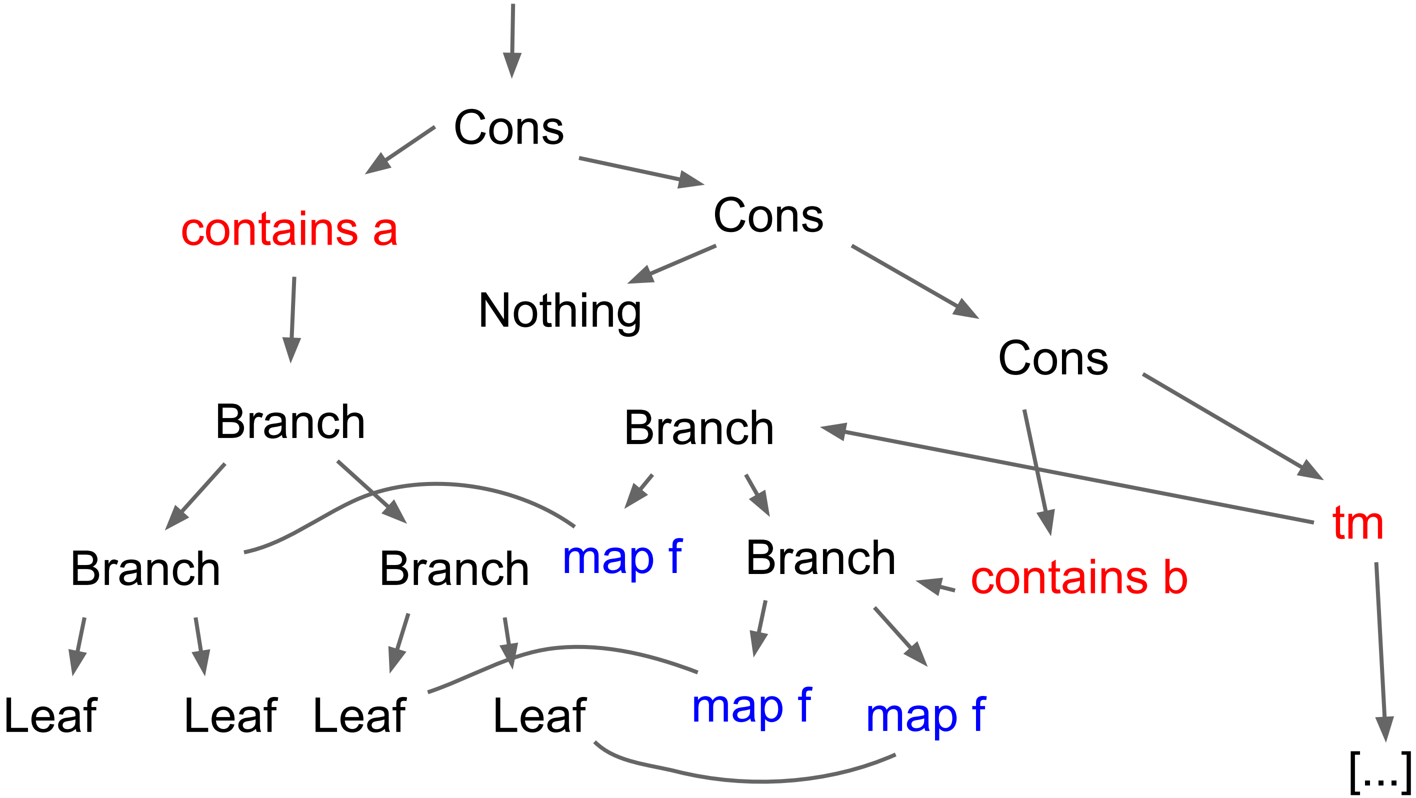
Concurrent Transaction Processing



Concurrent Transaction Processing



Concurrent Transaction Processing



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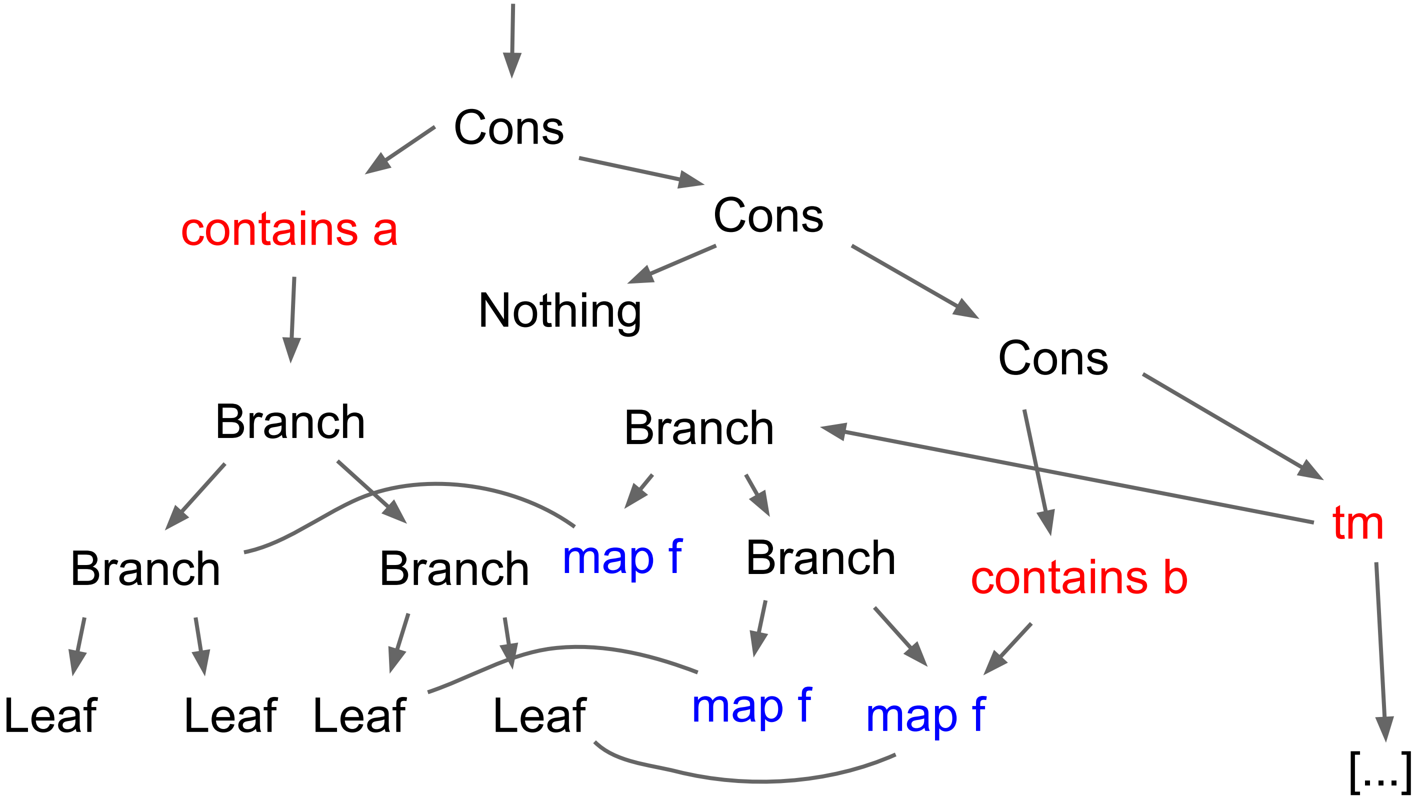
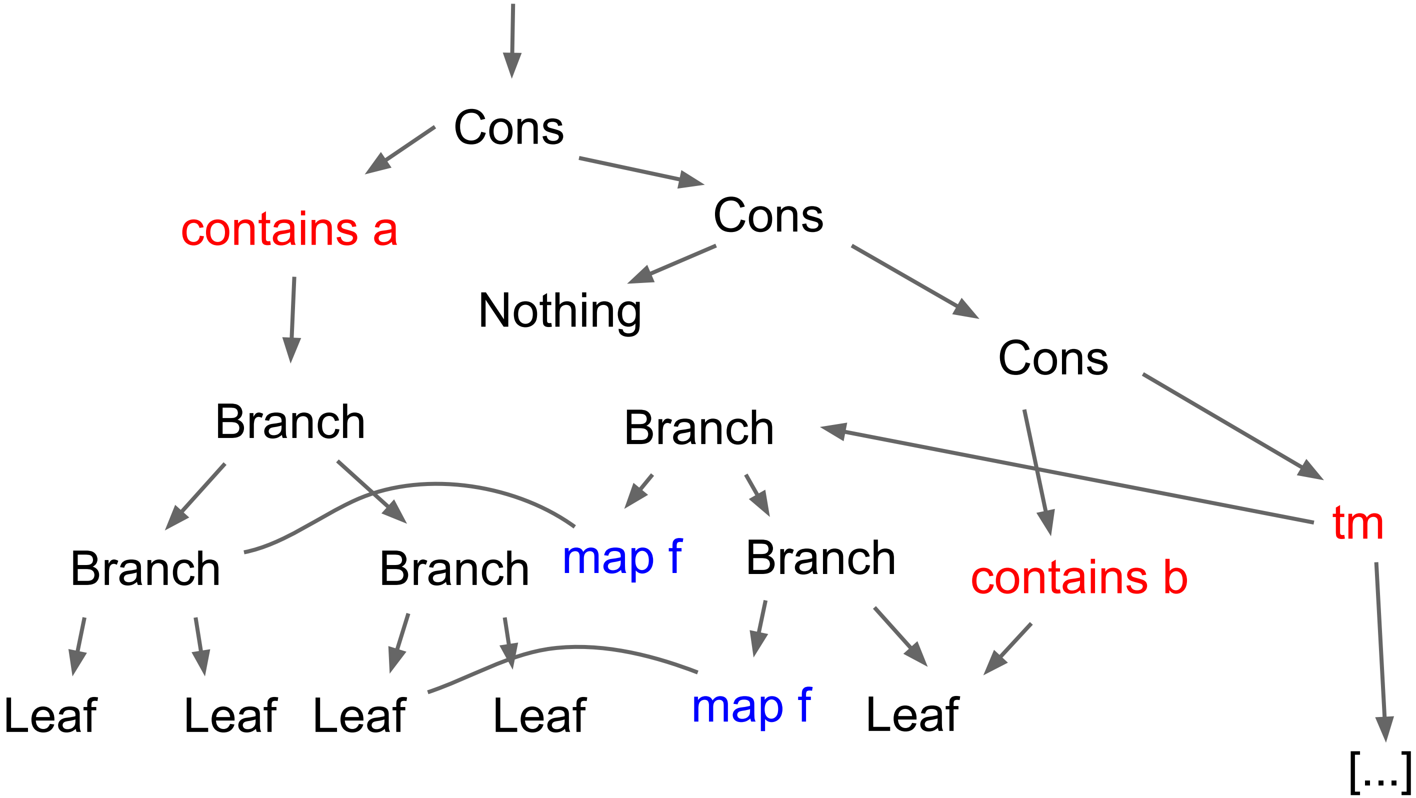


Concurrent Transaction Processing



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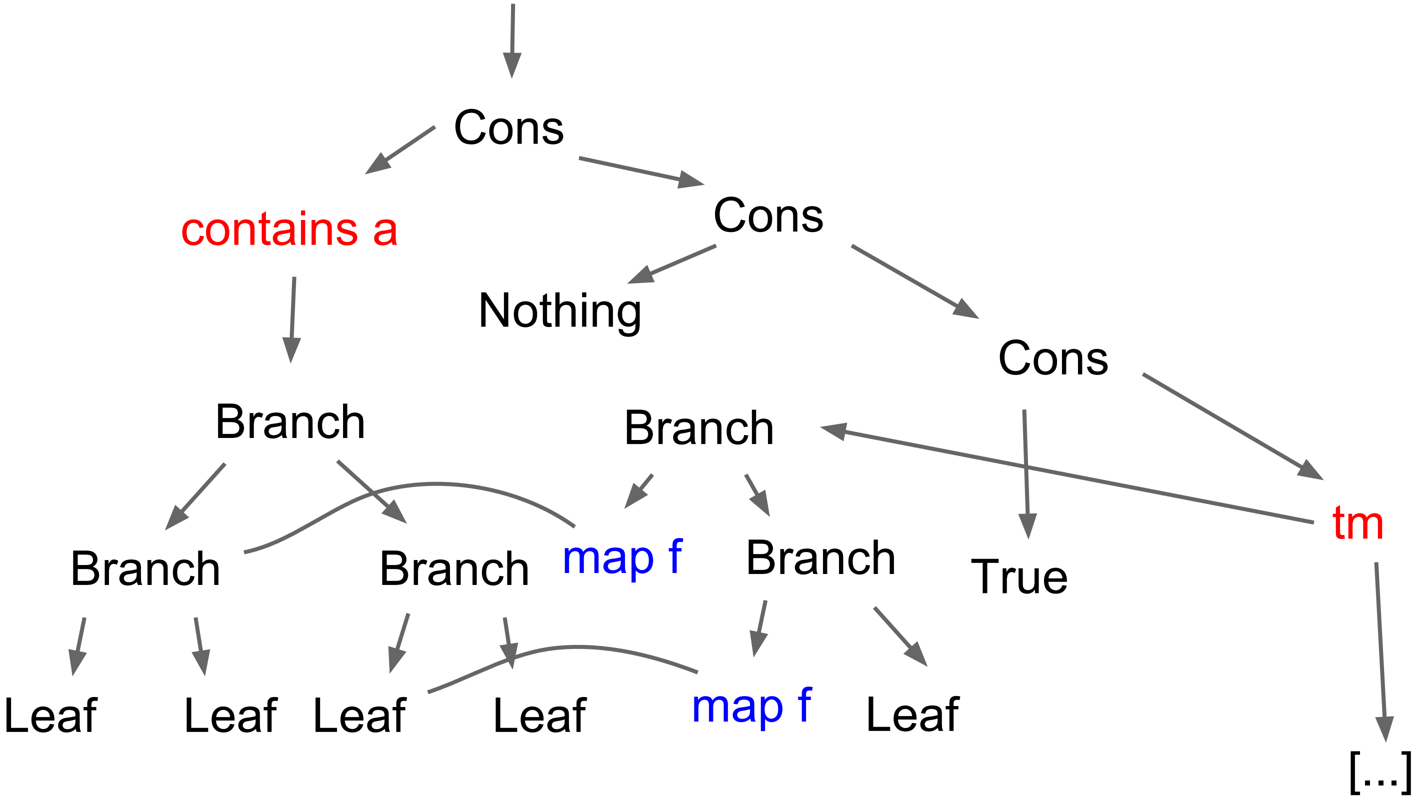

Limitations of lazy evaluation

- Concurrency is limited by data dependencies

  e.g. `if c then a else b`

  can not be evaluated until `c` is evaluated
- Transaction functions must be total
- Memory requirements

Future work: Memoization

Remember results of function applications:

- Optimistic execution & retrying transactions
- Aggregate functions:
  - sum, min, max, …
  - constraint checks
- Materialized views

Persistent Functional Languages

ACID-State for Haskell implements many of these ideas, however:

- There are no ad-hoc transactions:
  - We can’t do schema changes on the fly
  - We can’t share the state with other programs
- GHC not optimized for this use case
  - State is limited to main memory
  - Task scheduling not optimized for latency

Persistent Functional Language

Goals:

- Functional transaction processing
- Ad-hoc transactions
- Stored transactions (domain specific API)

Binding Model

The state consists of a set of bindings.

A transaction can atomically:

- Create, update and delete bindings
- Evaluate an expression in the current state

Persistent Functional Language

Demo

Conclusions

We have seen:

- Functional languages for transaction processing
- Persistent functional languages

Future work:

- Optimistic concurrency control & Memoization
- Online Schema Changes
- Modelling relational databases
- Verification of constraints

Functional Persistent Languages

New possibilities:

- New methods of concurrency control
- Verification of database software

Concurrent Transaction Execution

Latency > Throughput

Concurrency > Parallelism

Transactions should be able to make progress.

Avoid transactions blocking each other.

Blocking: Heavy computations, IO

Functional States

We model states using algebraic data types, e.g.:

```
data List a
  = Cons a (List a)
  | Nil

data Tree k v
  = Branch k (Tree k v) (Tree k v)
  |  Leaf k v
```

Combined Approach

```
var state = new AtomicReference(initial_state)
def execute(tx : S -> (S, R, R)) : R = {
    var ns, r, f
    do {
        val s = state.get()
        (ns, r, f) = tx(s)
        reduce(f)
    } while(!state.compareAndSet(s, ns))
    return r
}
```

Application: Online Schema Transformations

Current database systems can only do schema transformations offline.

We want to perform schema changes lazily

Future Work: Modelling Relational Databases

Model: relations, relational operations, indices, constraints, …

Querying using list comprehensions

Specifying updates conveniently

Concurrent updates

Typing relational operations

Future Work:
Verifying Database Software

Runtime constraint verification to eliminate runtime checks.

Example?

Future Work: Optimistic Execution

```
var state = new AtomicReference(initial_state)
def execute(tx : S -> (S, R, F)) : R = {
    var ns, r, f
    do {
        val s = state.get()
        (ns, r, f) = tx(s)
        reduce(f)
    } while(!state.compareAndSet(s, ns))
    return r
}
```