There's Nothing Wrong with Out-of-Thin-Air: Compiler Optimization and Memory Models

Clark Verbrugge*
Allan Kielstra†
Yi Zhang*

*McGill University
†IBM Toronto Lab

Introduction

- Memory (consistency) models
  - Important part of concurrent systems
    - Concurrent hardware
    - Concurrent languages
  - Define ordering, visibility of R/W

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- Java Memory Model
  - Revised in 2005
    - Well-defined semantics
    - Allow most/reasonable compiler optimizations
  - Multiple flaws
    - Proposed fixes

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- Java Memory Model
  - Revised in 2005
    - Well-defined semantics
    - Allow most/reasonable compiler optimizations
  - Multiple flaws
    - Proposed fixes
- Fundamental concerns for optimization

Contents

- Two problems the JMM creates for optimization

    1. Racey programs
    2. Non-racey programs

- A language proposal
    - Example
- Conclusions & Future Work

The Problem (1)

- "Out-of-Thin-Air"
  - A consequence of simplistic MM semantics

```
x = y = 0;

Thread 1        Thread 2
r1 = x;         r2 = y
y = r1;         x = r2;
```

[Manson et al., 2005]

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r1 == r2 == ...?
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  - Avoid out-of-thin-air values
    - Ensure causality for all visible values

The Problem with the Solution (1)

- What about compiler optimization?
  - Remember, we want to allow many opts!
  - But compiler opts reuse space...
    - Speculative optimizations
    - Advanced, algorithmic improvements
      - e.g. ...

The Problem with the Solution (1)

```
x.f = 0;
for (int i=0;i<UPPER;i++) {
    if (x.a[i]) ++x.f;
}
```

- If lots of true values, a more efficient version:

```
x.f = UPPER;
for (int i=0;i<UPPER;i++) {
    if (!x.a[i]) --x.f;
}
```

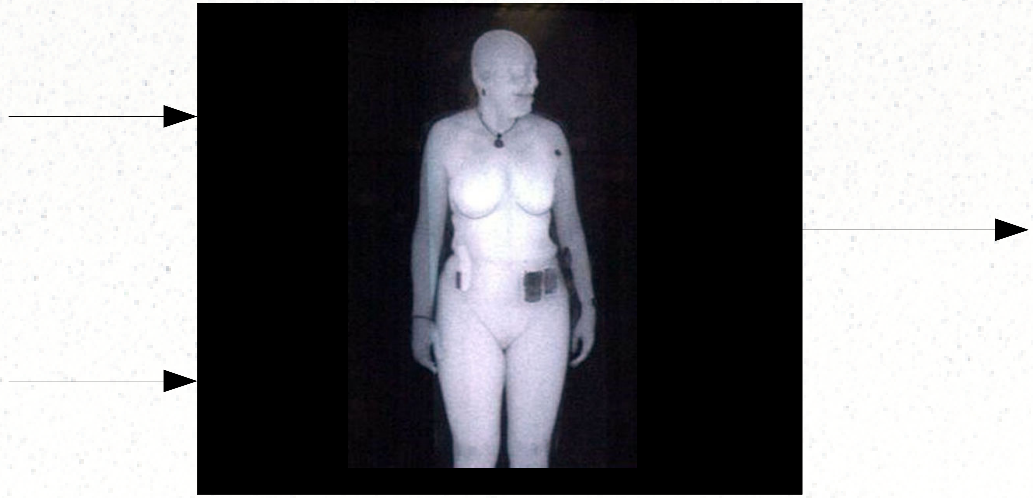
  - Fewer writes!
  - But now there are out-of-thin-air values...
    - x.f contains UPPER...n *vs* 0..n

The Problem with the Solution (1)

- A surprisingly deep problem!
  - Traditional compiler opts only promise *functional equivalence*
    - Same input, same output

The Problem with the Solution (1)

- Out-of-thin-air guarantees opens this up
  - A variable which cannot be *proved* thread-private, may be arbitrarily *observed*
    - And so must not contain out-of-thin-air values



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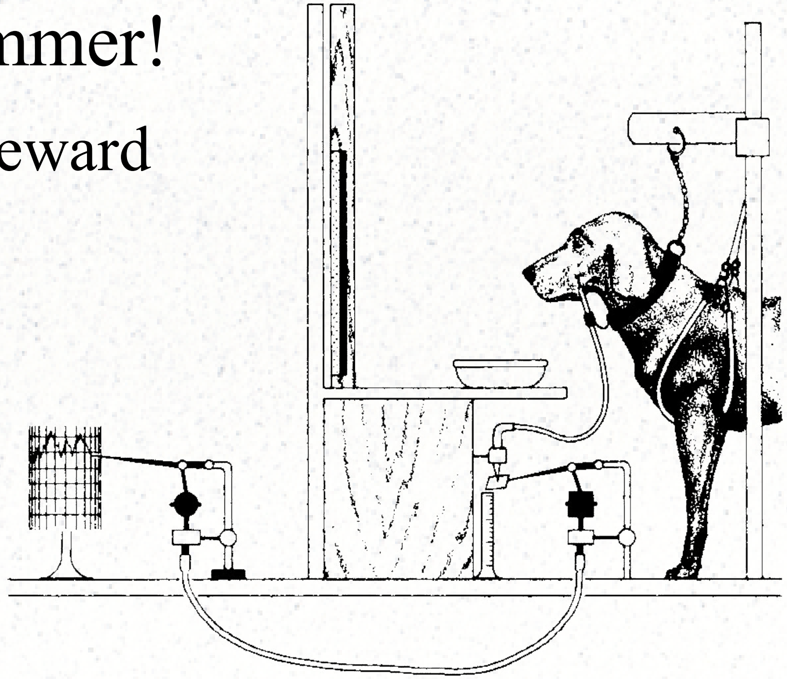
  - Program has no data races (DRF)
  - Good programmer!
    - Give a reward



The Solution (2)

- Sequential Consistency for DRF
  - A wonderful property!
    - Program is correctly synchronized
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  - A wonderful property!
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    - DRF implies SC
    - Programmer understands behaviour!
  - Considered *The Fundamental Property*
    - C++, Java, ...

The Problem with the Solution (2)

- DRF is a *runtime* property
  - Not a static one

```
                    x = y = 0;
Thread 1                         Thread 2

do {                             do {
  r1 = x;                          r2 = y;
} while (!r1);                   } while (!r2);
y = 42;                          x = 42;
```

[Manson et al., 2005]

  - Above program is DRF through *divergence*
    - Notice write to y (resp. x) is not dependent on the loop...

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Thread 1            Thread 2
y = 42;             x = 42;
do {                do {
  r1 = x;             r2 = y;
} while (!r1);      } while (!r2);
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[Manson et al., 2005]

  - No longer DRF...
    - Disallow these opts?

The Problem with the Solution (2)

- Lots of optimizations move code through control-flow
  - Partial Redundancy Elimination
  - Global code scheduling
  - ....
- New step in optimization strategy
  - Determine runtime control flow
    - Step 1: Solve the halting problem...

The Problem with the Solutions

- Of course we can handle both problems:
  - Conservative race detection
  - DRF-preserving optimizations
- Expensive
  - Accurate conflict detection is hard!
- Optimization quality depends on conflict detection

A Solution to the Problem with the Solutions

- Why not make visibility guarantees explicit?
  - Statically declare shared data
  - Compiler knows what it can do
- Race-free by design
- Borrow ideas from OpenMP, UPC, etc.
  - Not backward compatible in general

A Race-Free Java

- Syntactic change:
  - Use “volatile” declaration for all shared data
- Semantic change:
  - All non-volatile data is thread-specific
    - Every thread has its own copy

A Race-Free Java

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class Q {
  volatile Object x;
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volatile P v;
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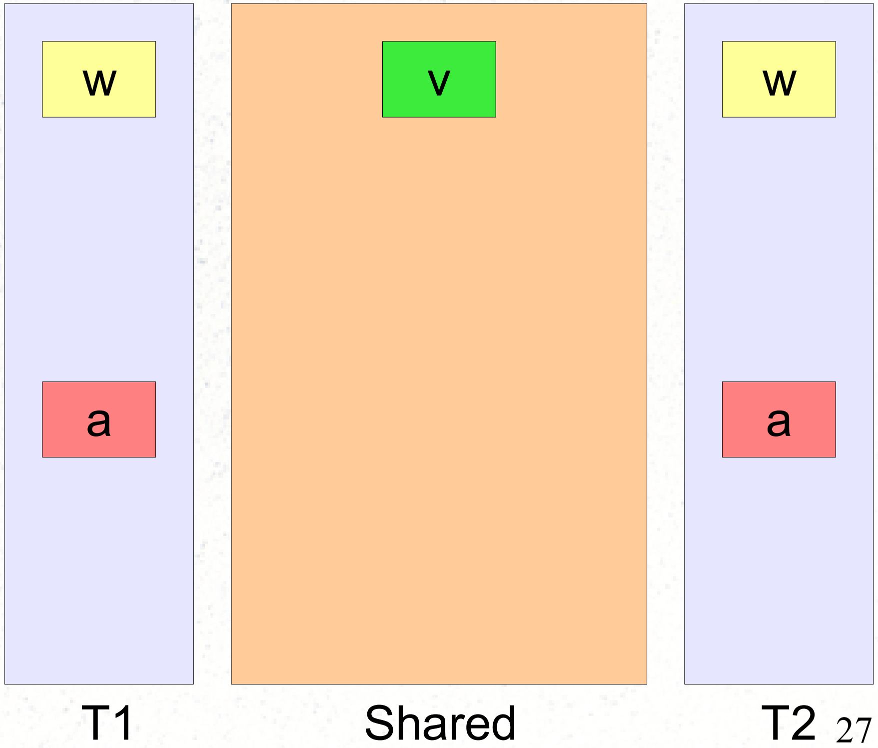

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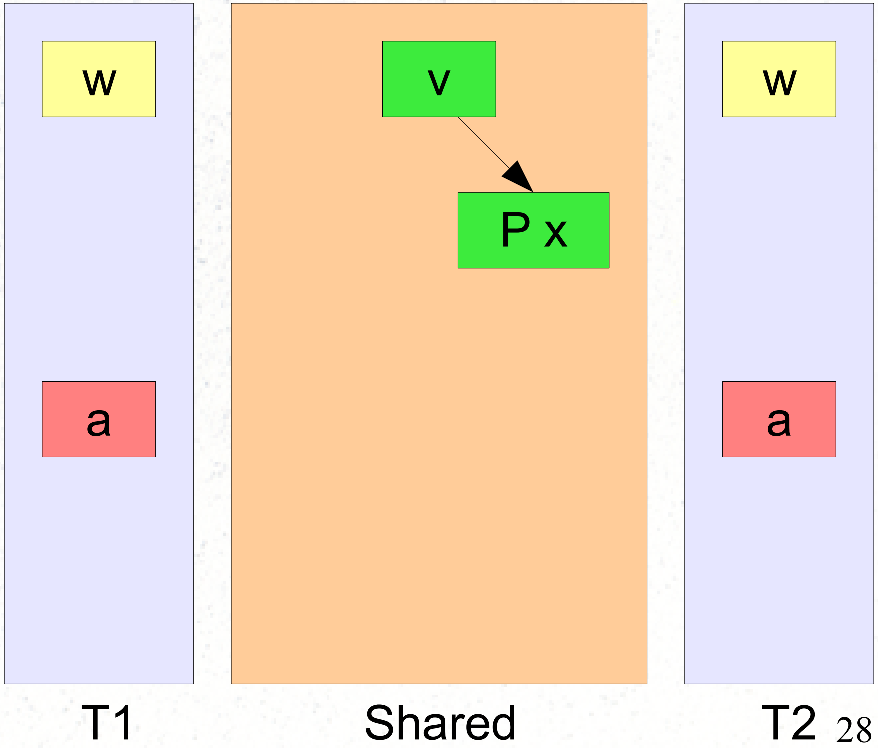

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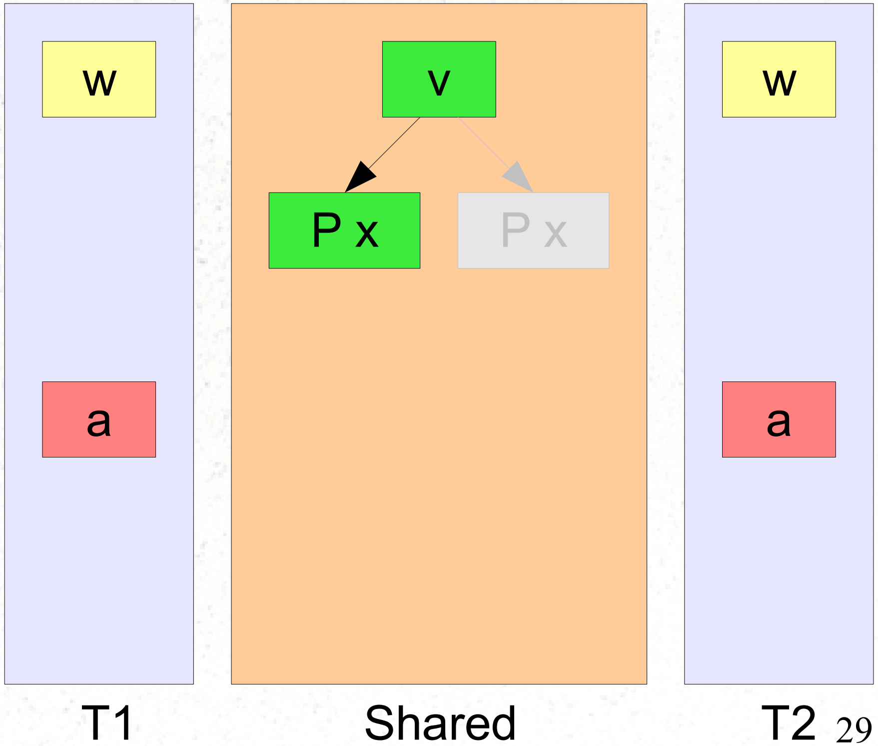

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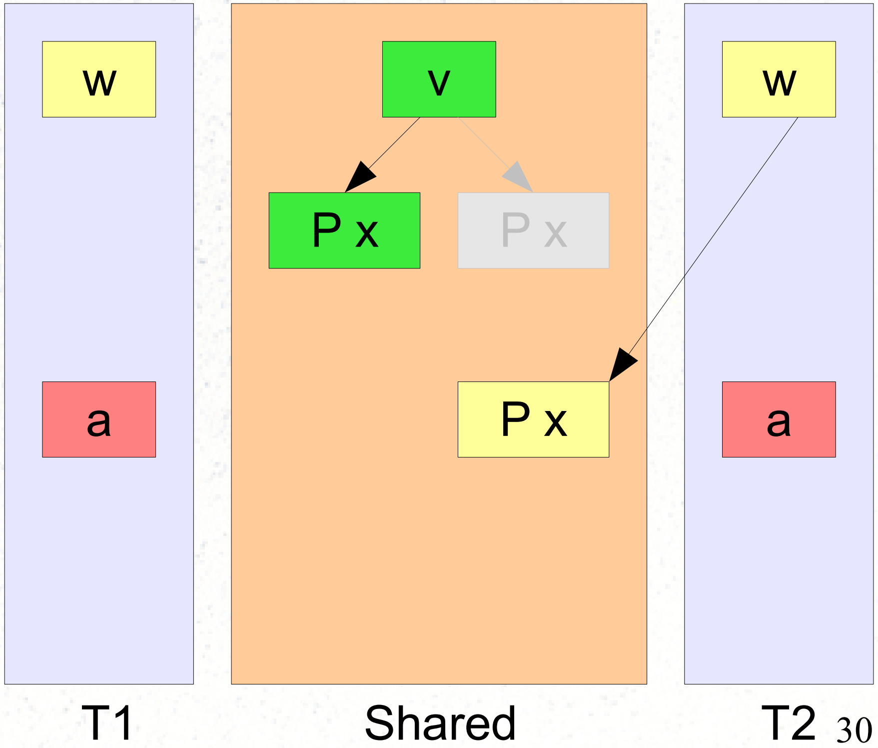

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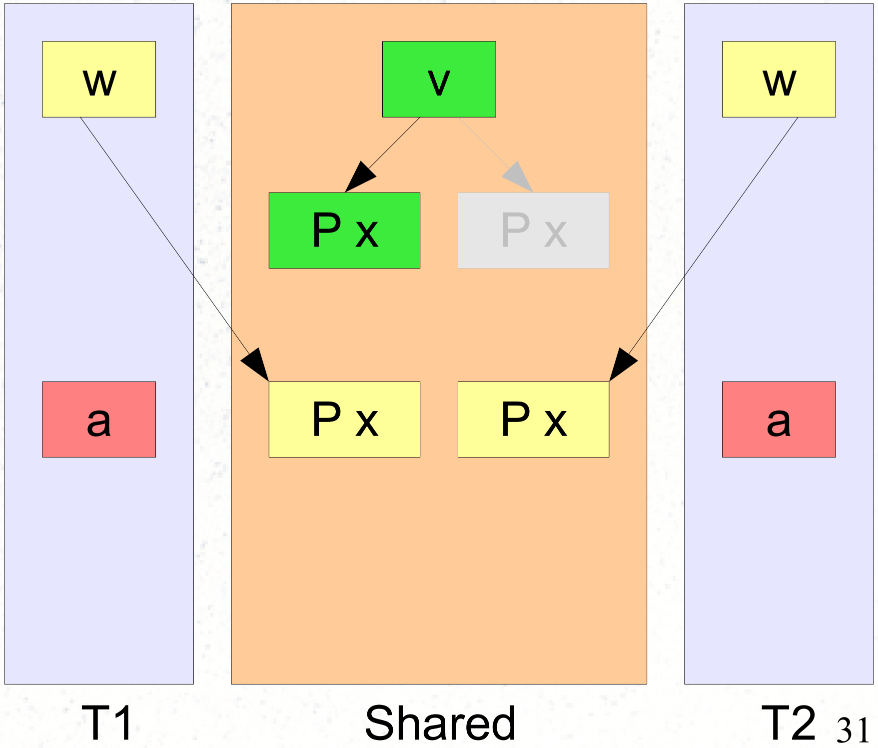

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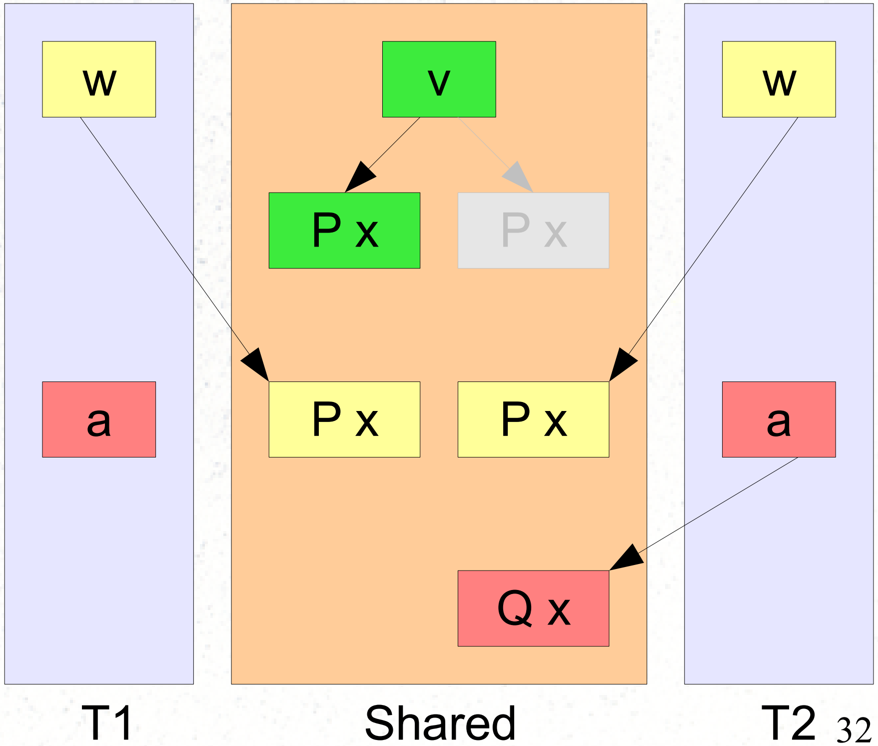

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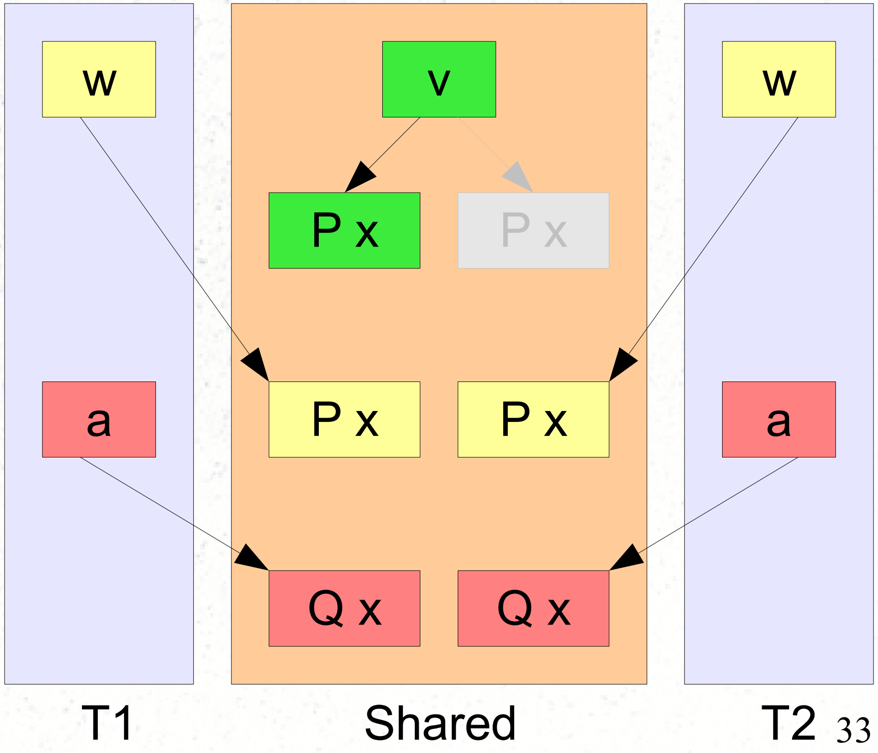

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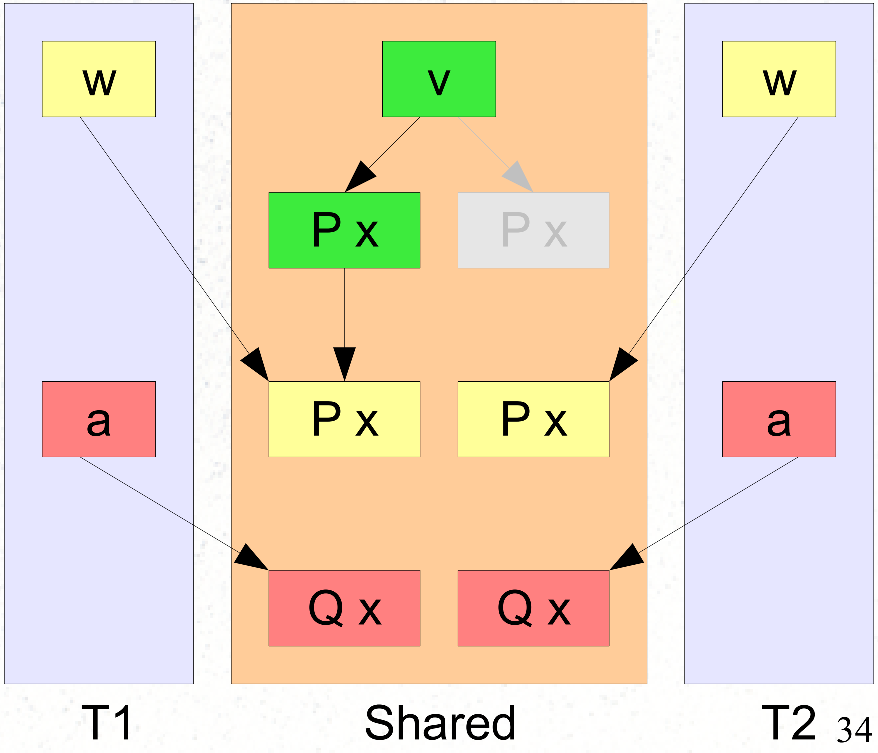

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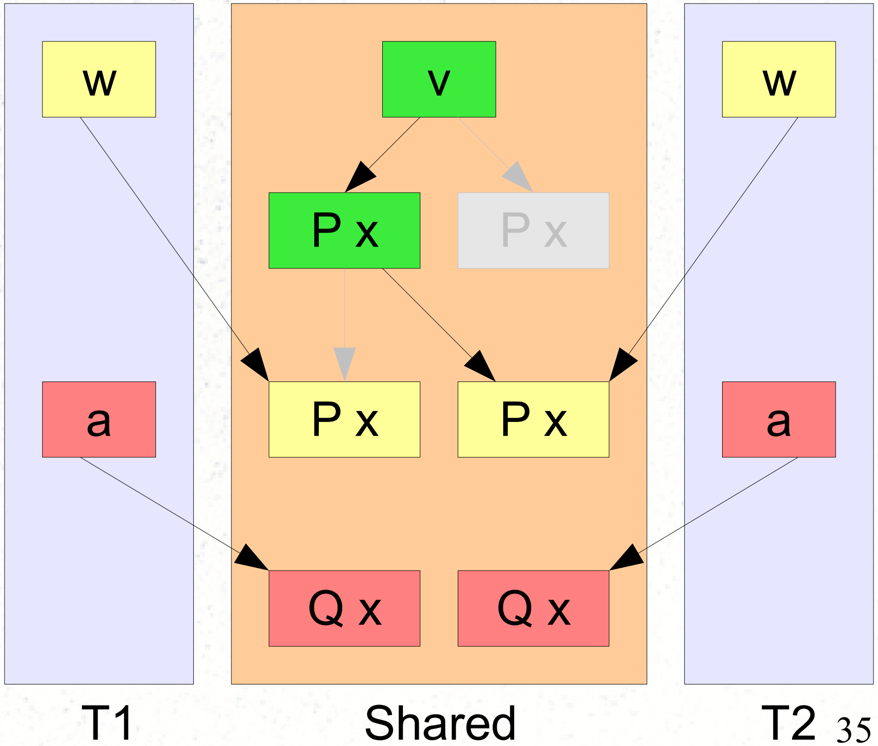

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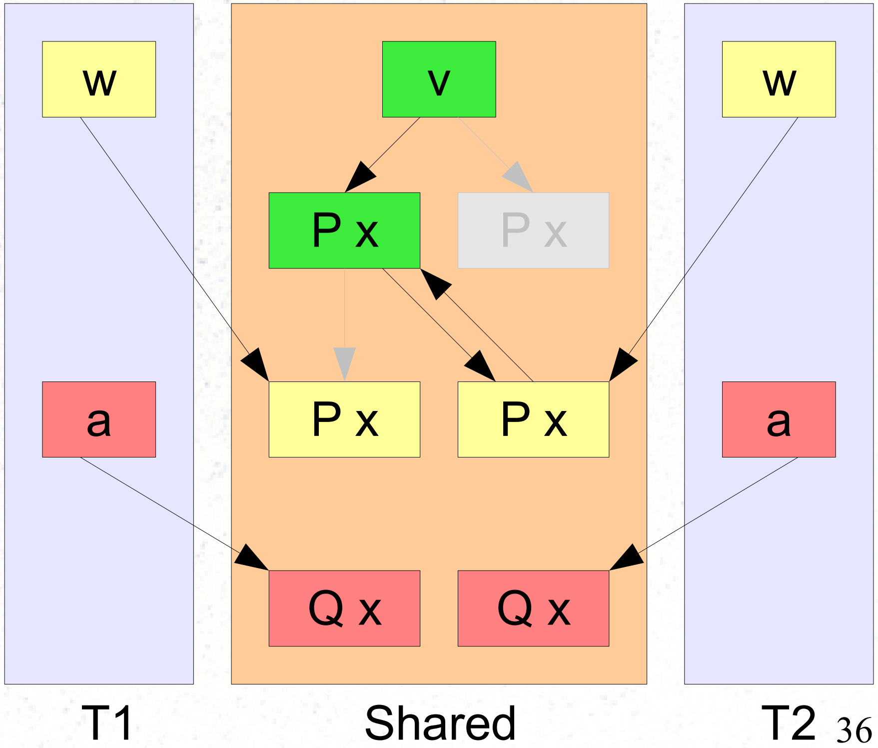

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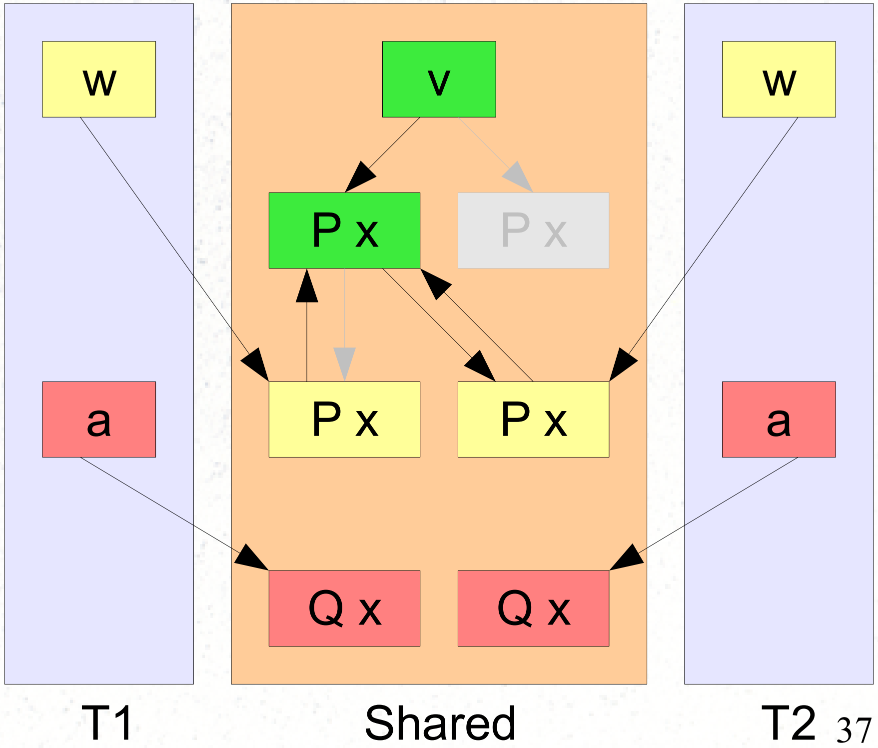

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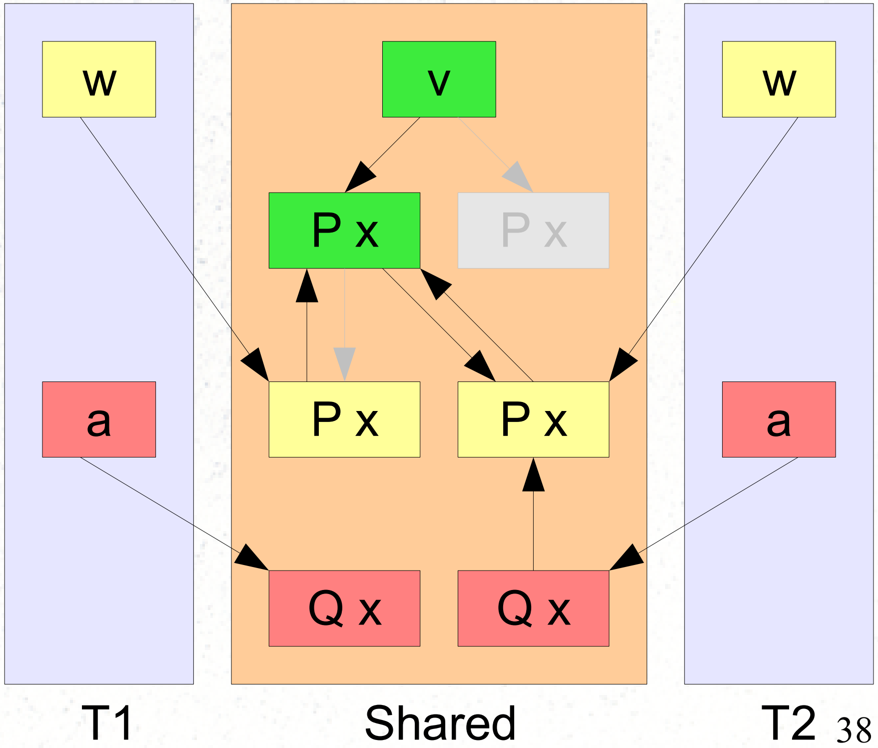

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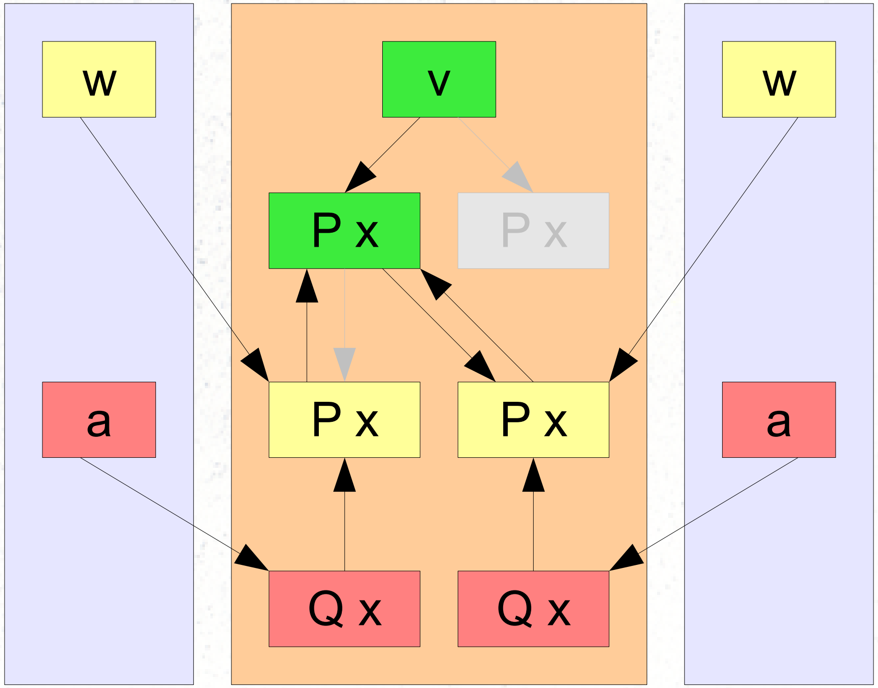

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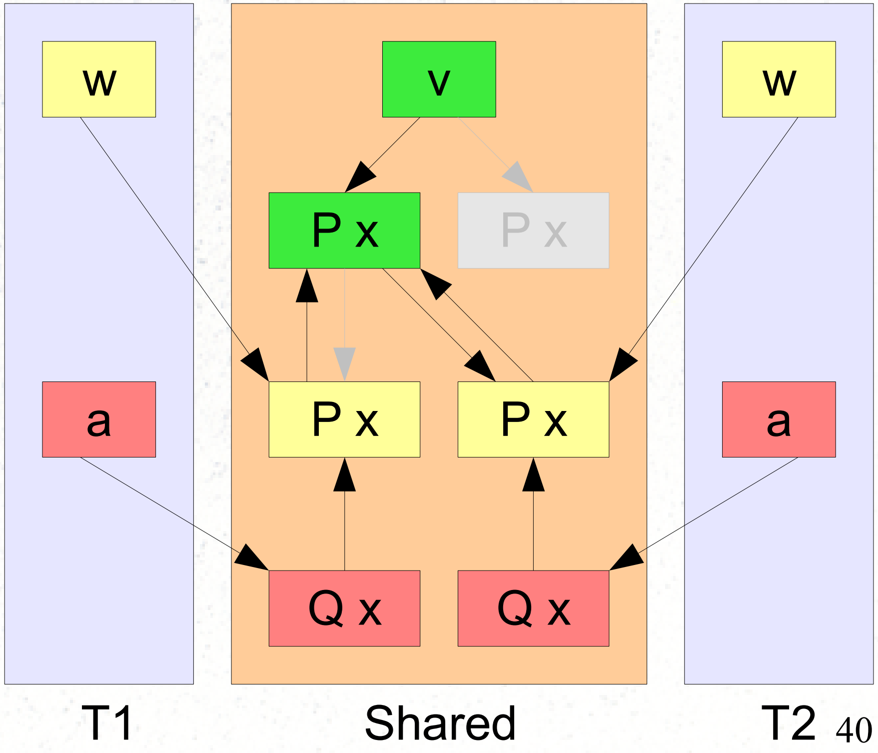

A Race-Free Java

- SC and DRF as a language given
- Makes correctness a baseline
  - Still can optimize
    - Reduce/eliminate volatile requirements
    - But starting from a trivially known safe state

A Race-Free Java

- Lots of issues to think about
  - Shared to/from local
  - Different copy in/out semantics?
  - Type system changes
  - GC impact
  - Synchronization (locks)
    - Separate atomicity from visibility requirements

Conclusions

- Need to do *something*
  - JMM too restrictive
    - Observability requirements are subtle
  - Conservative safety restricts optimization
- Basic dichotomy in optimization approach

  a) Start from unknown, prove safe, optimize

  b) Start from trivially safe, optimize

Future Work

- Fully develop the language
  - Explore larger examples
    - Need to show programmability too!
  - Prototype compiler
    - Work underway using JikesRVM
- Optimize thread-local/specific data
  - Including copy-in/out models

Thank You

Questions?