# Dynamic Software Updates: A VM-Centric Approach

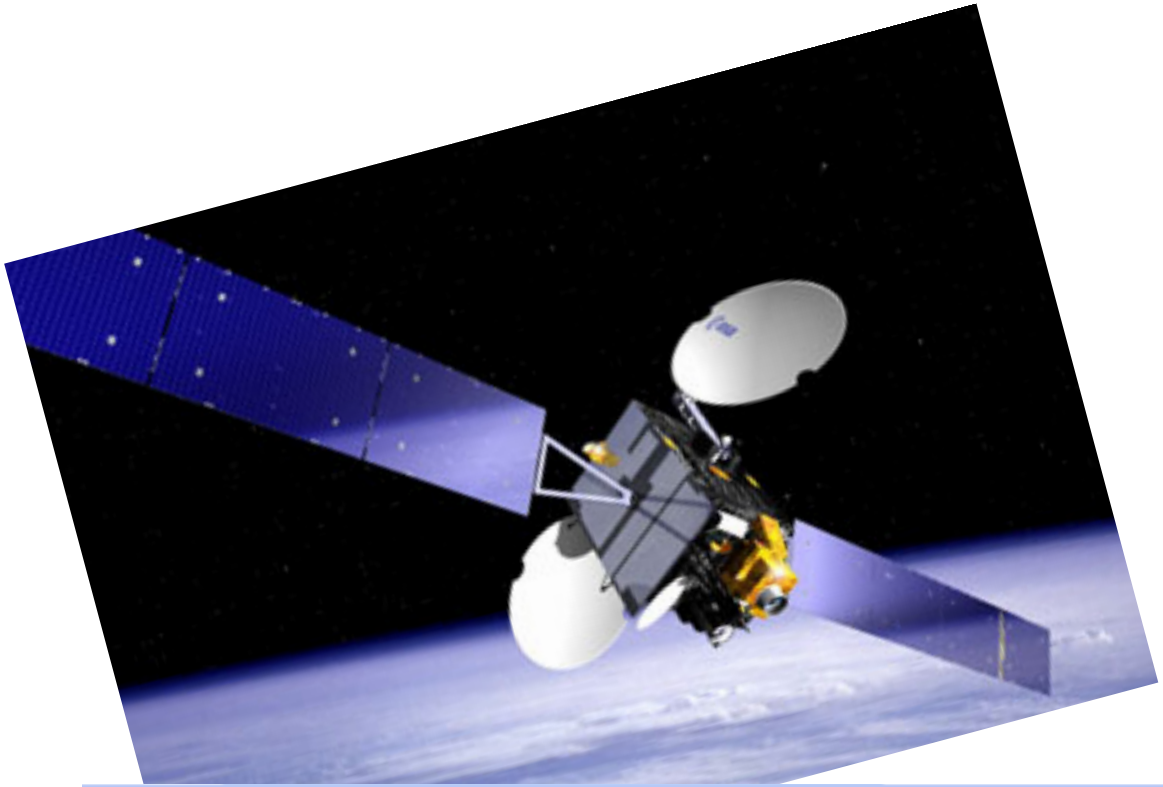
Suriya Subramanian

Intel Corporation

Feb 26, 2013

# Motivation

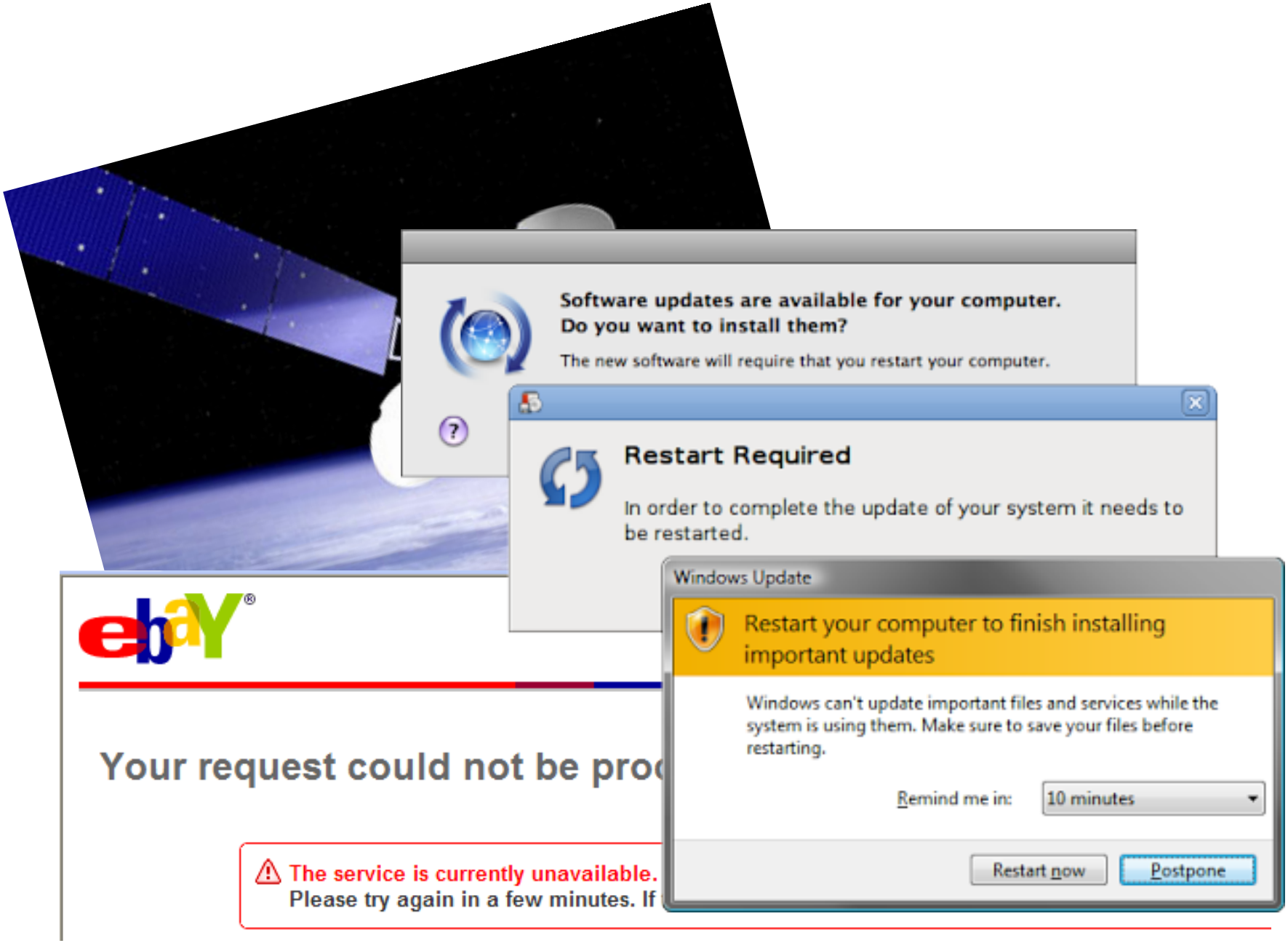
- Software applications change all the time
- Deployed systems must be updated with bug fixes, new features
- Updating typically involves: stop, apply patch, restart



ebay

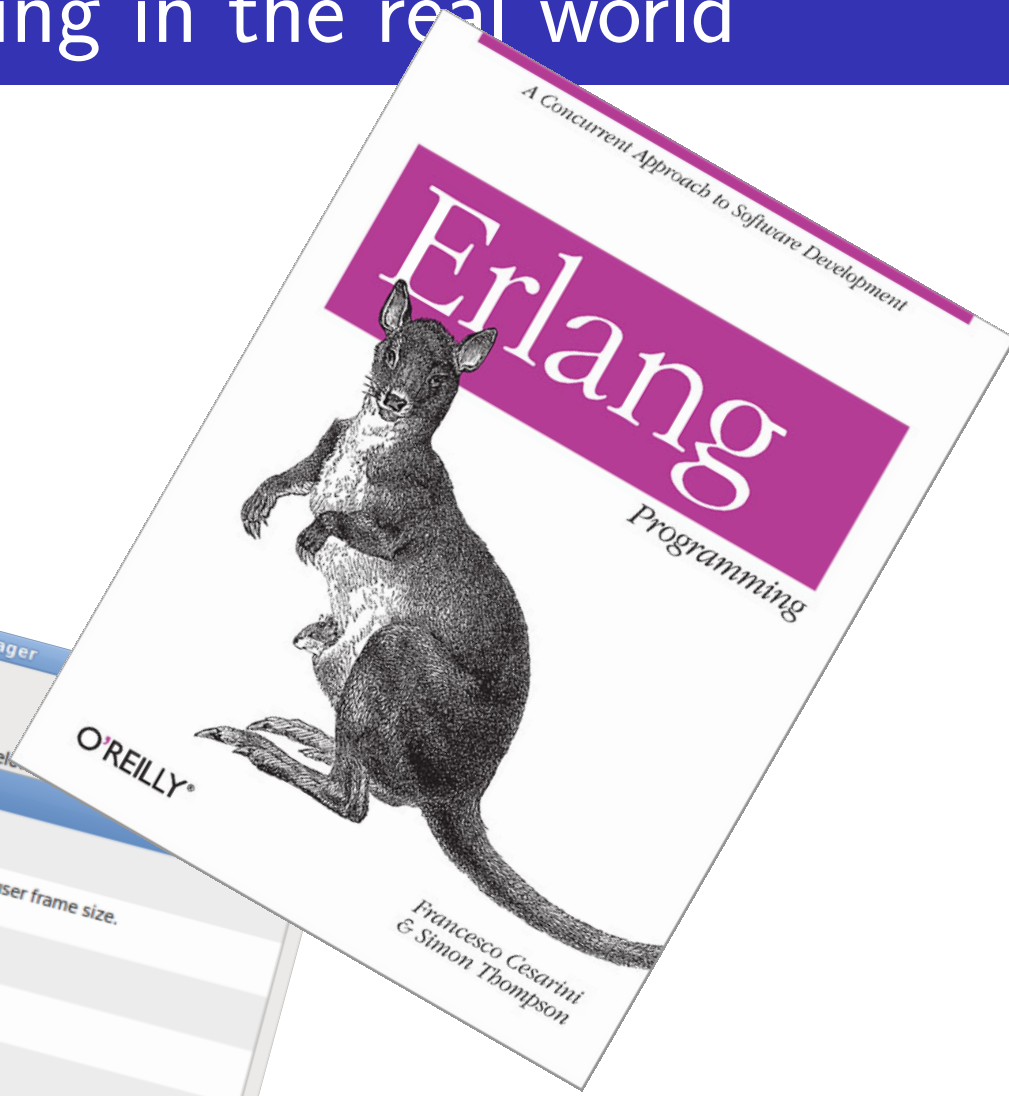
## Your request could not be processed at this time

⚠ The service is currently unavailable.
Please try again in a few minutes. If this problem persists, report an issue to eBay support.

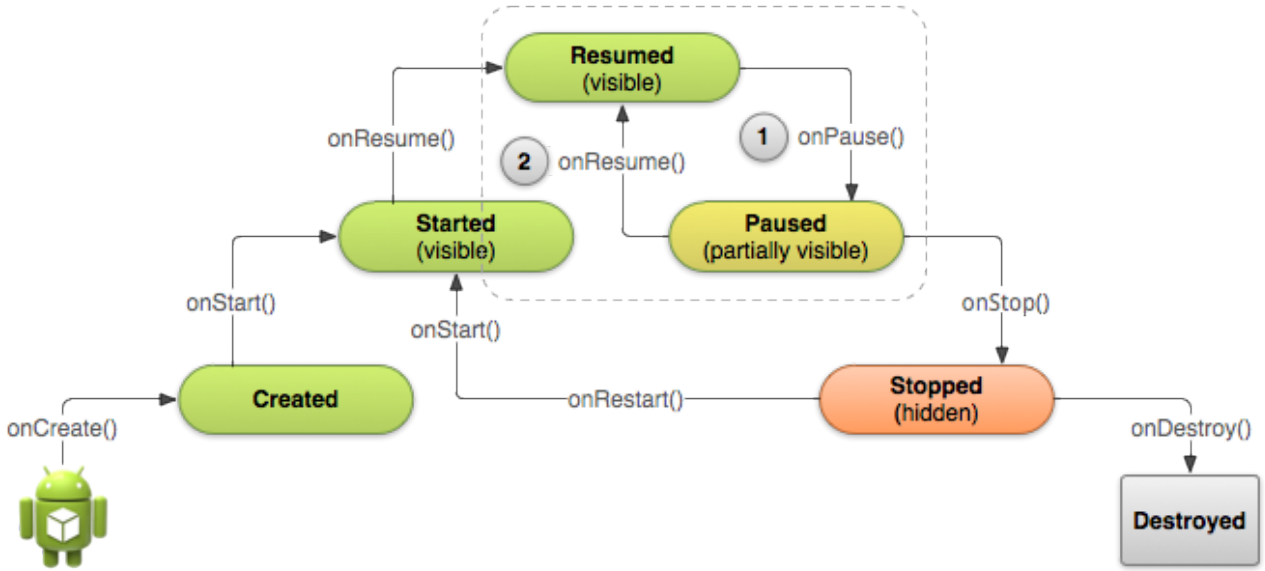

Software updates are available for your computer.
Do you want to install them?
The new software will require that you restart your computer.
Restart Required
In order to complete the update of your system it needs to be restarted.
Windows Update
Restart your computer to finish installing important updates
Windows can't update important files and services while the system is using them. Make sure to save your files before restarting.
Remind me in:
10 minutes
Restart now
Postpone
ebay
Your request could not be proc
The service is currently unavailable.
Please try again in a few minutes. If

# Dynamic Software Updating in the real world

mozilla LABS
Jetpack

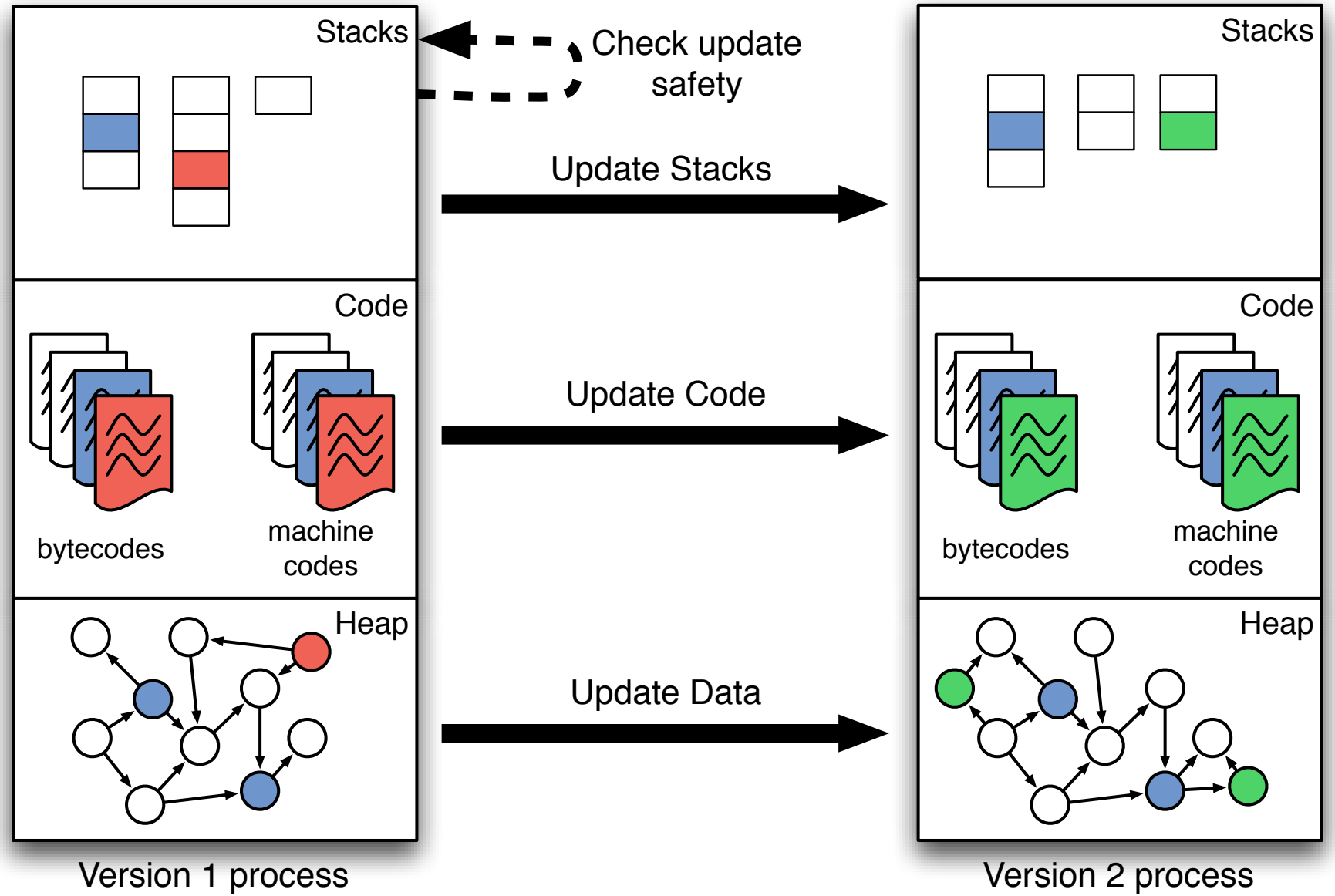



# Dynamic Software Updating in the real world



The fundamental problem is losing state because of downtime.

# Dynamic software updating



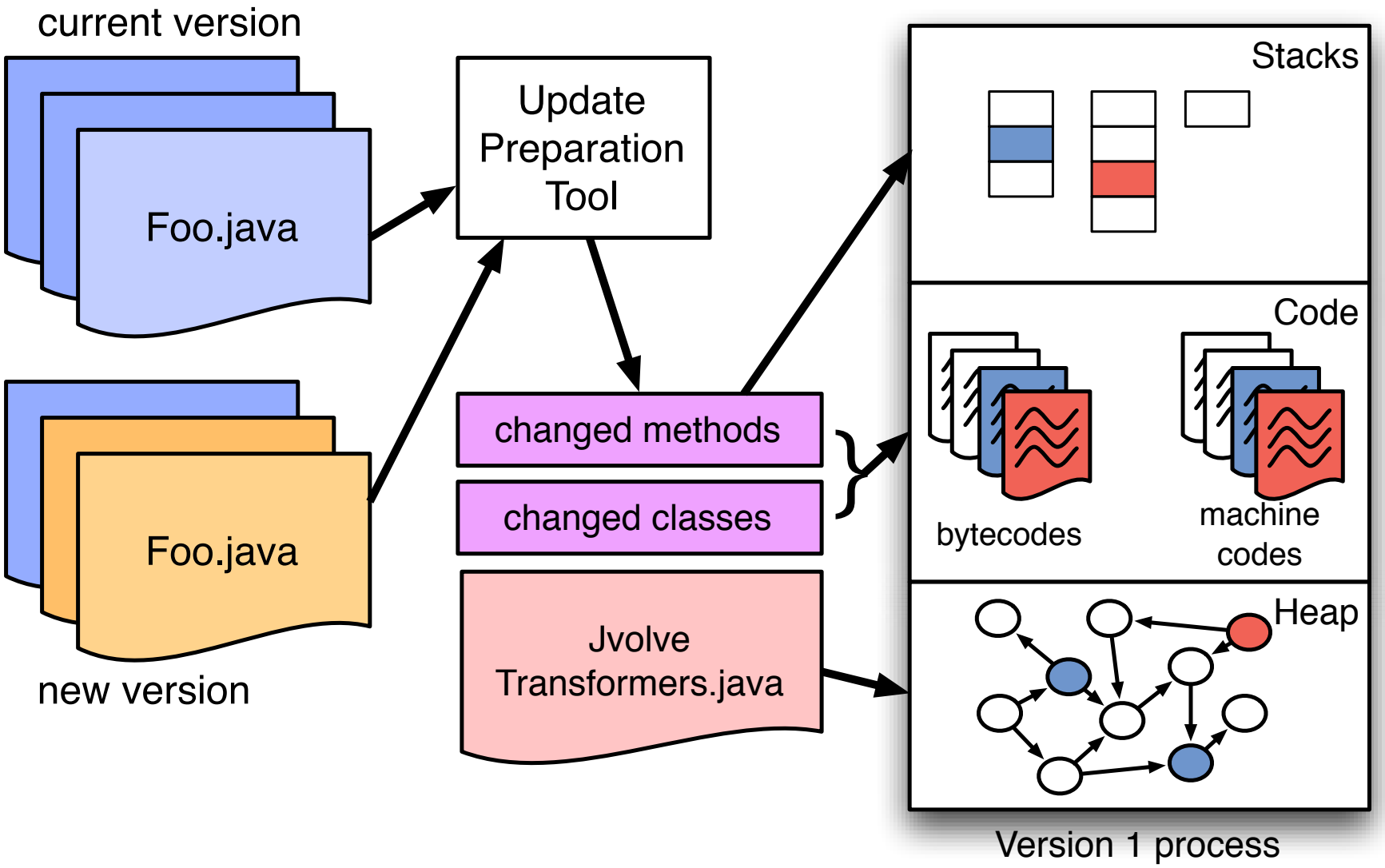
# Key contribution

JVOLVE - a DSU-enabled Java Virtual Machine

| | |
|---|---|
| Safe | Guarantees type-safe updates<br>Relies on programmer for semantic-correctness |
| Flexible | Supports method body and signature changes across class hierarchies |
| Efficient | No overhead during normal execution |
| Easy to use | The stock application is DSU-ready<br>No rewriting/recompilation required |

# Outline

# JVOLVE - System overview



# Supported updates

- Changes within the body of a method

```
  public static void main(String args[]) {
    System.out.println("Hello, World.");
+   System.out.println("Hello again, World.");
  }
```

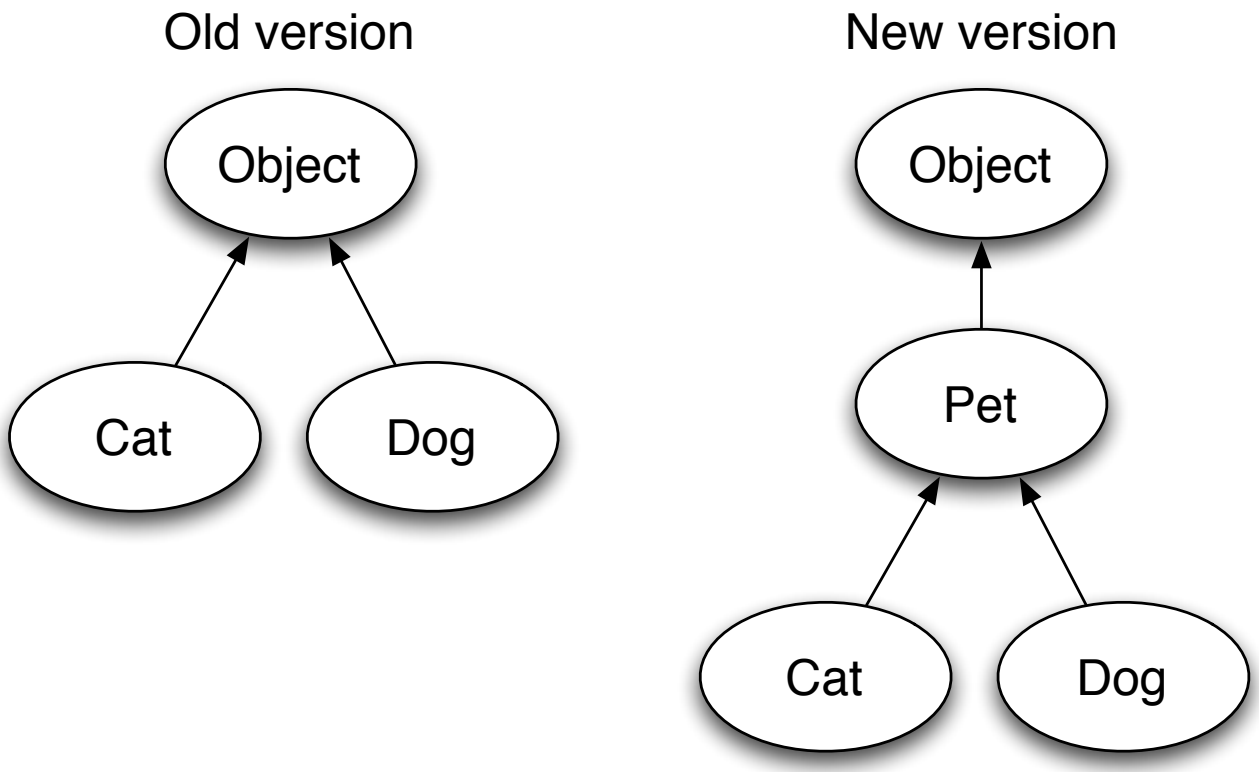
- Class signature updates
  - Add, remove, change the type signature of fields and methods

```
  public class Line {
-   private final Point2D p1, p2;
+   private final Point3D p1, p2;
    ...
  }
```

- Signature updates require an object transformer function
- Changes can occur at any level of the class hierarchy

# Unsupported changes

- Renaming classes
- Changes to class hierarchy



# Example of an update (JavaEmailServer)

```
  public class User {
    private final String username, domain, password;
-   private String[] forwardAddresses;
+   private EmailAddress[] forwardAddresses;
    public User(...) {...}
    public String[] getForwardedAddresses() {...}

    public void setForwardedAddresses(String[] f) {...}

  }

  public class ConfigurationManager {
    private User loadUser(...) {
        ...
        User user = new User(...);
        String[] f = ...;

        user.setForwardedAddresses(f);
        return user;
    }
  }
```

# Example of an update (JavaEmailServer)

```
  public class User {
    private final String username, domain, password;
-   private String[] forwardAddresses;
+   private EmailAddress[] forwardAddresses;
    public User(...) {...}
-   public String[] getForwardedAddresses() {...}
+   public EmailAddress[] getForwardedAddresses() {...}
-   public void setForwardedAddresses(String[] f) {...}
+   public void setForwardedAddresses(EmailAddress[] f) {...}
  }

  public class ConfigurationManager {
    private User loadUser(...) {
        ...
        User user = new User(...);
-       String[] f = ...;
+       EmailAddress[] f = ...;
        user.setForwardedAddresses(f);
        return user;
    }
  }
```

# Example of an update (JavaEmailServer)

```
public class v131_User {
  private final String username, domain, password;
  private String[] forwardAddresses;
}
public class JvolveTransformers {
 ...
 public static void jvolveClass(User unused) {}
 public static void jvolveObject(User to, v131_User from) {
    to.username = from.username;
    to.domain = from.domain;
    to.password = from.password;
    // to.forwardAddresses = null;
    int len = from.forwardAddresses.length;
    to.forwardAddresses = new EmailAddress[len];
    for (int i = 0; i < len; i++) {
      to.forwardAddresses[i] =
        new EmailAddress(from.forwardAddresses[i]);
}}}
```

Stub generated by UPT for the old version

Default transformer copies old fields, initializes new ones to `null`

# Example of an update (JavaEmailServer)

```
public class v131_User {
  private final String username, domain, password;
  private String[] forwardAddresses;
}
public class JvolveTransformers {
 ...
 public static void jvolveClass(User unused) {}
 public static void jvolveObject(User to, v131_User from) {
    to.username = from.username;
    to.domain = from.domain;
    to.password = from.password;
    // to.forwardAddresses = null;
    int len = from.forwardAddresses.length;
    to.forwardAddresses = new EmailAddress[len];
    for (int i = 0; i < len; i++) {
      to.forwardAddresses[i] =
        new EmailAddress(from.forwardAddresses[i]);
}}}
```

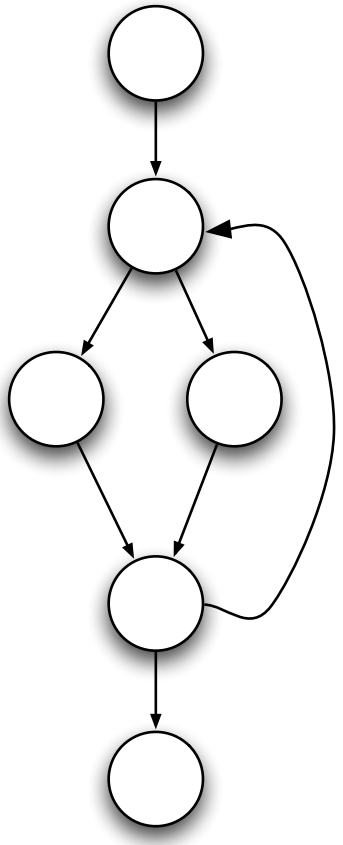
Stub generated by UPT for the old version

# Update process


- Offline Update Preparation Tool
- JVOLVE VM
  - Reach a DSU safe point
  - Install new classes
  - Update state
  - Resume execution

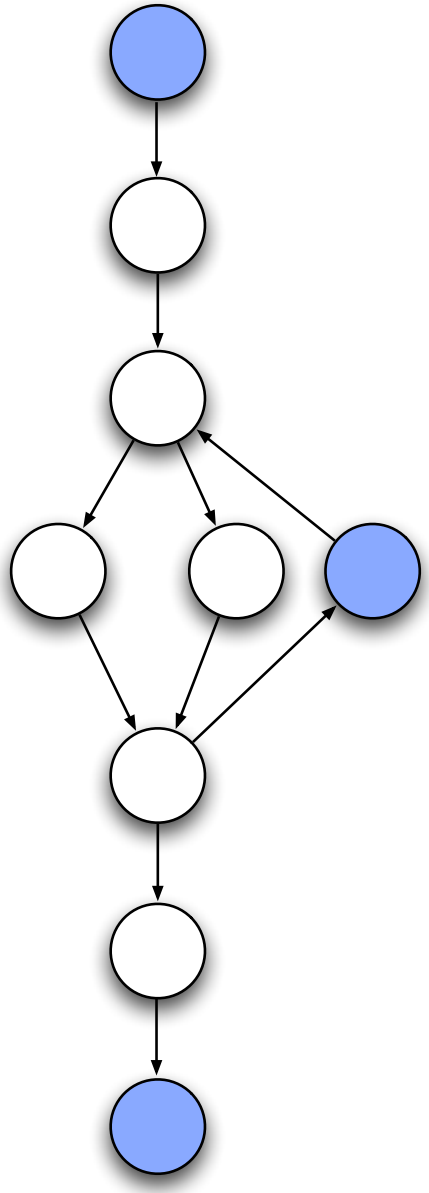
# Safe point for the update

- Updates happen at “safe points”
- Safe points are VM yield points,
  and restrict what methods can be on stack
- Extend the thread scheduler to
  suspend all application threads
- If any stack has a restricted method,
  delay the update



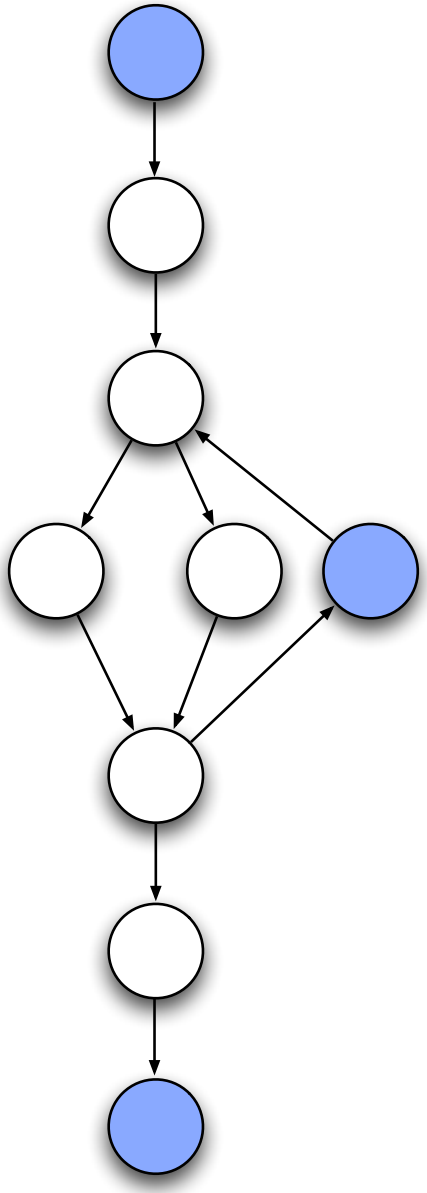
# Safe point for the update

- Updates happen at “safe points”
- Safe points are VM yield points,
  and restrict what methods can be on stack
- Extend the thread scheduler to
  suspend all application threads
- If any stack has a restricted method,
  delay the update



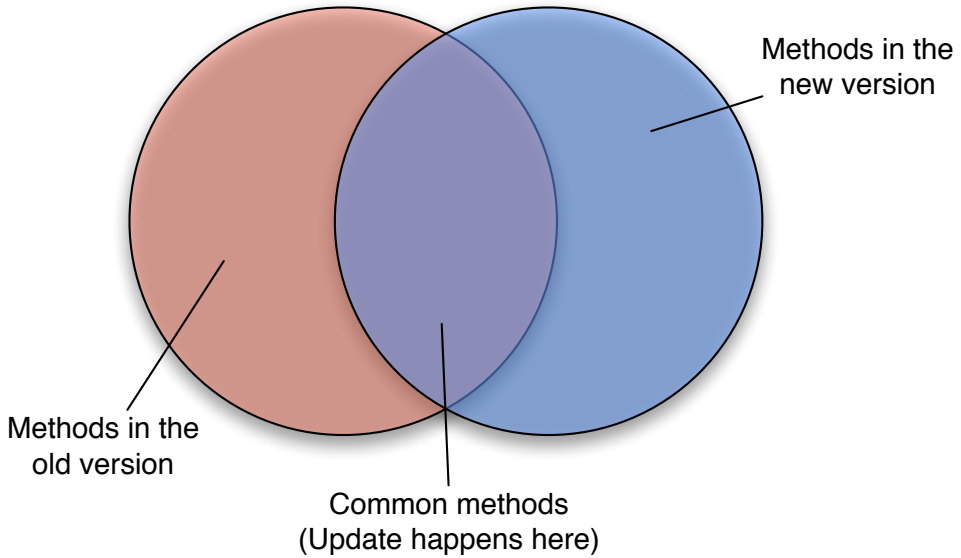
# Safe point for the update

- Updates happen at “safe points”
- Safe points are VM yield points,
  and restrict what methods can be on stack
- Extend the thread scheduler to
  suspend all application threads
- If any stack has a restricted method,
  delay the update



# Restrict changed methods (activeness safety)

- Update happens atomically
- Only old code runs before update, only new after update
- Do not allow changed methods to be active on stack
- Guarantees type safety
- Old and new version methods are independently type-safe



# Restricted methods

(1) Methods changed by the update

(2) Methods identified by the user as unsafe based on semantic information about the application

Install return barriers that trigger DSU upon unsafe method's return

(3) Methods whose bytecode is unchanged, but compiled representation is changed by the update

- Offsets of fields and methods hard-coded in machine code
- Inlined callees may have changed

Utilize on-stack replacement to recompile base-compiled methods

# Restricted methods

(1) Methods changed by the update

(2) Methods identified by the user as unsafe based on semantic information about the application

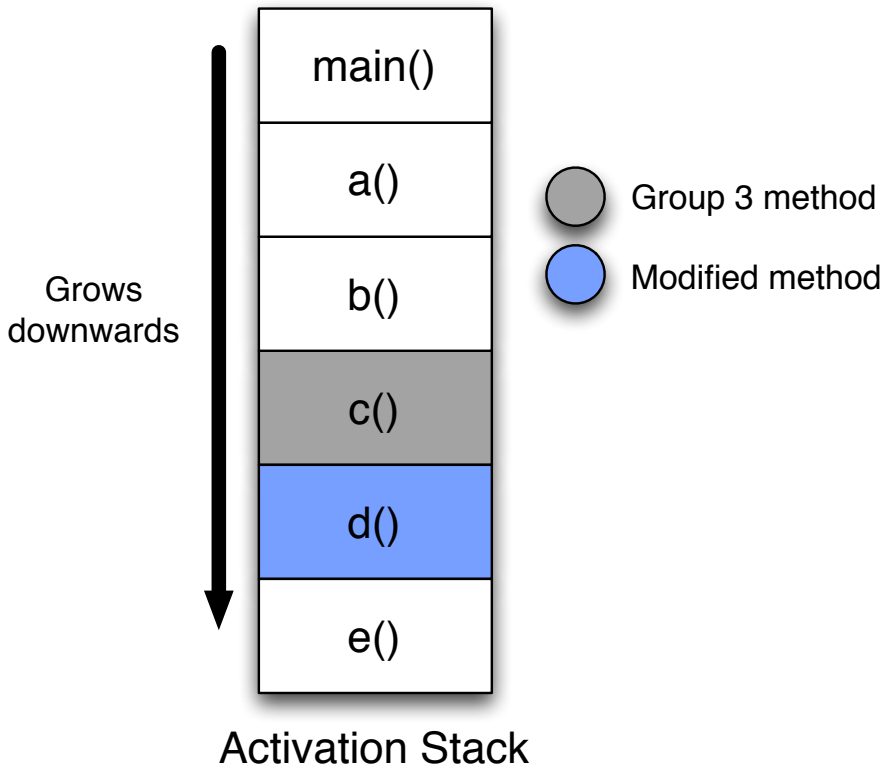
Install return barriers that trigger DSU upon unsafe method's return

(3) Methods whose bytecode is unchanged, but compiled representation is changed by the update

- Offsets of fields and methods hard-coded in machine code
- Inlined callees may have changed

Utilize on-stack replacement to recompile base-compiled methods

# Reaching a safe point



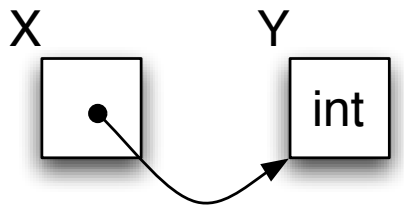

Install a return barrier for d(). Wait till it returns. On-stack replace new machine code for c().

# Outline

# Object Transformers Model

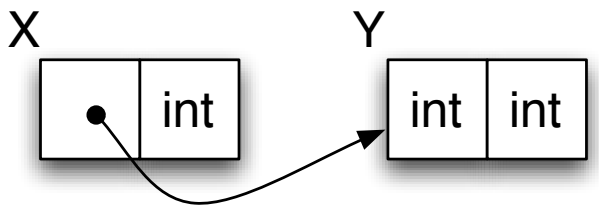
Old version

```
class X { Y y; }
class Y { int i; }
```




New version

```
class X { Y y; int z;}
class Y { int i; int j; }
```




```
1  Transformer for X:
2      to.y = from.y;
3      to.z = 0;
4  Transformer for Y:
5      to.i = from.i;
6      to.j = 0;
```

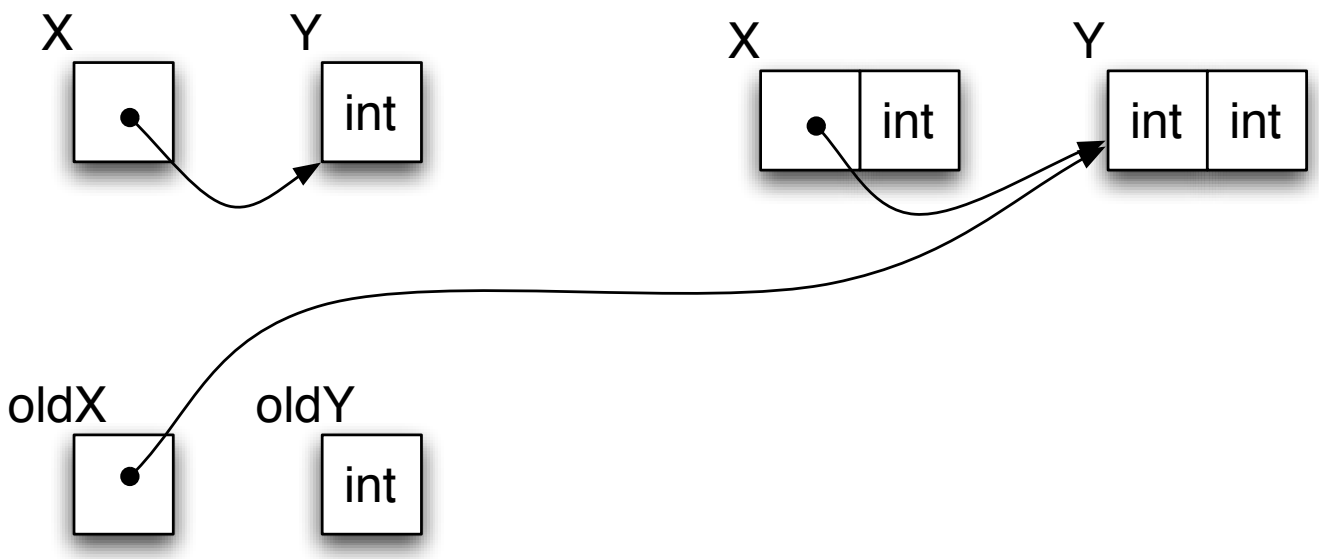
# Object Transformers Model

Old version

```
class X { Y y; }
class Y { int i; }
```

New version

```
class X { Y y; int z;}
class Y { int i; int j; }
```




Old version stub

```
class oldX { Y y; }
class oldY { int i; }
```

# Object Transformers Model

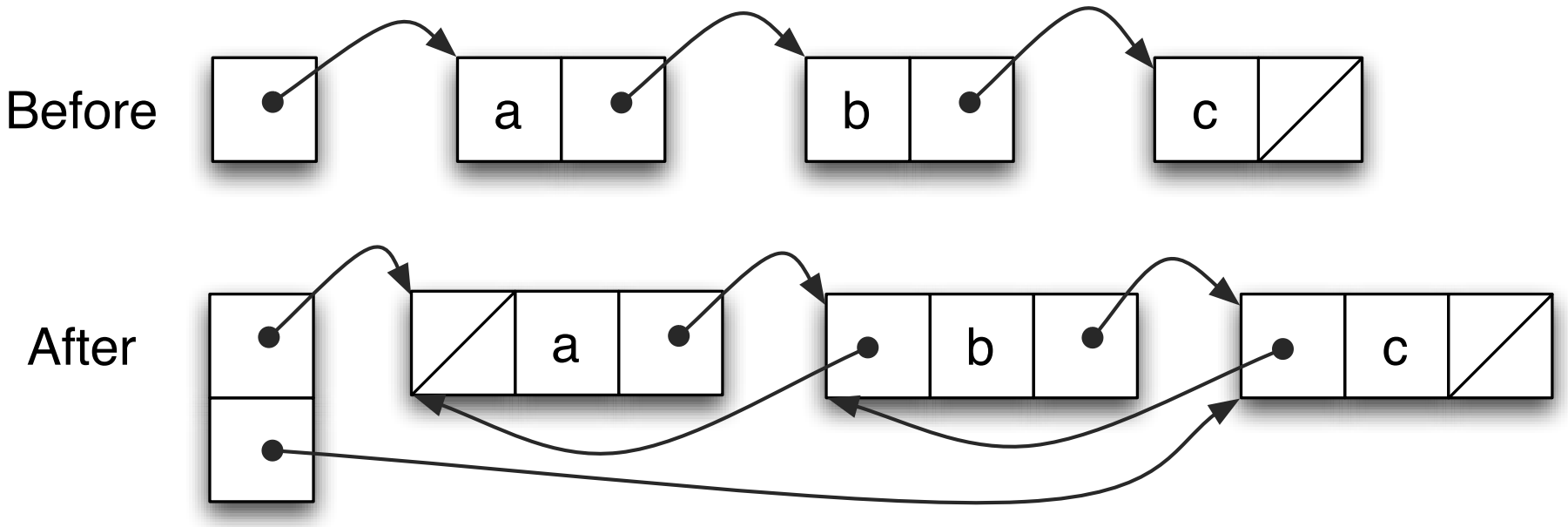
- Simple to reason about
- Transformers written in the source language
- All references are to the newest version
- Ensure that an object is transformed before reading its fields

# Transforming objects in the GC

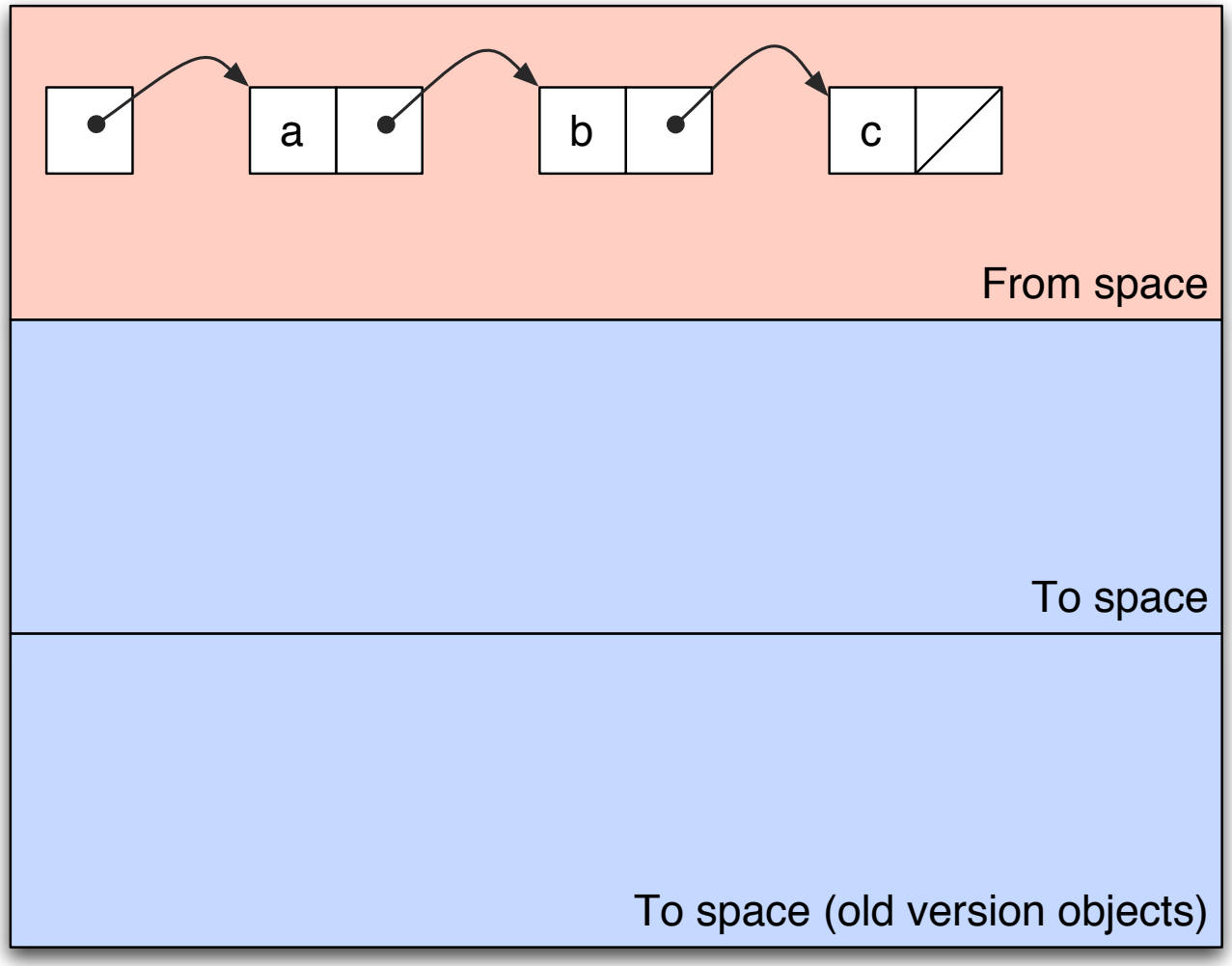
Happens in two steps

- Garbage collector creates an additional empty copy for updated objects
- Walk through and transform all these objects

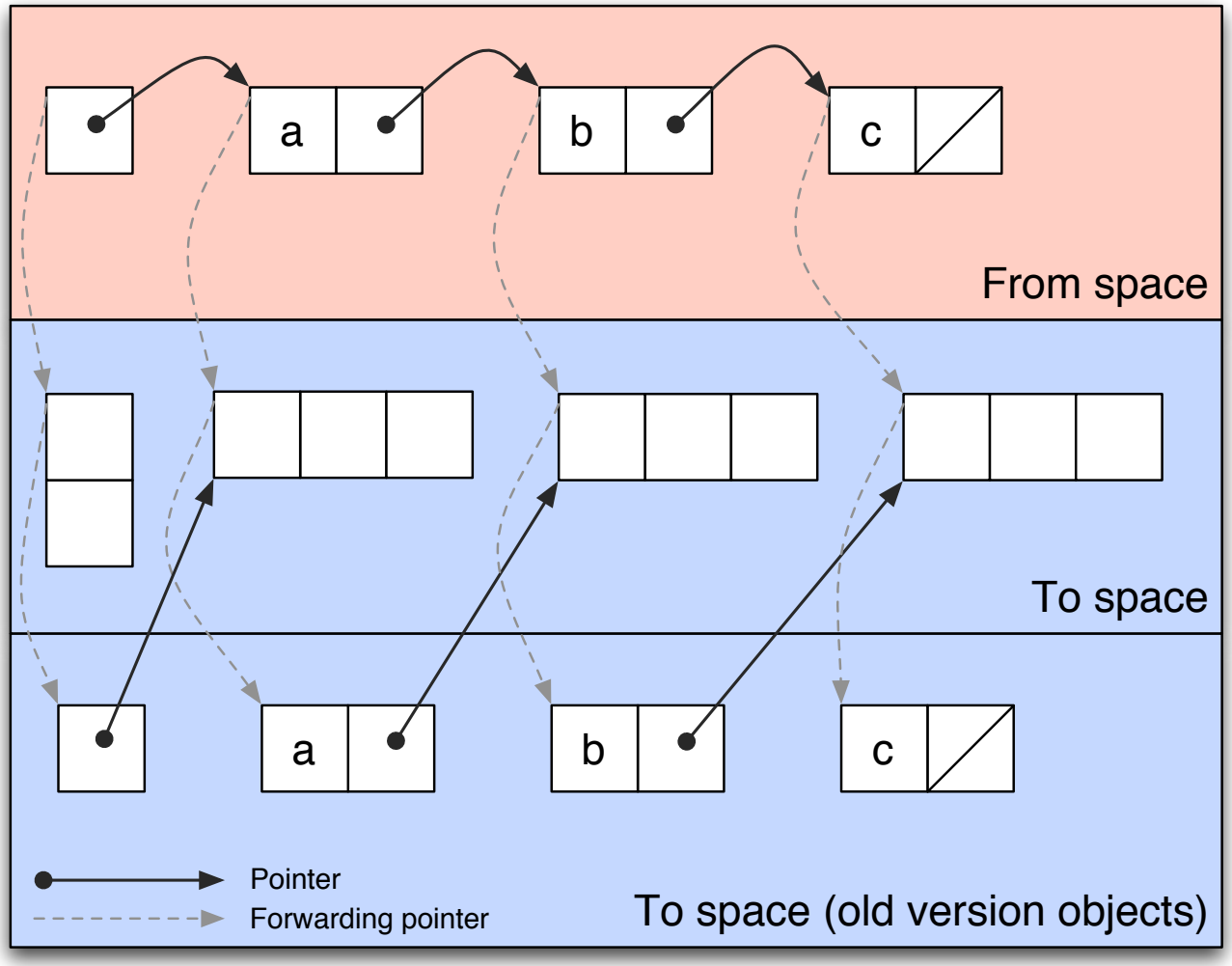
Example



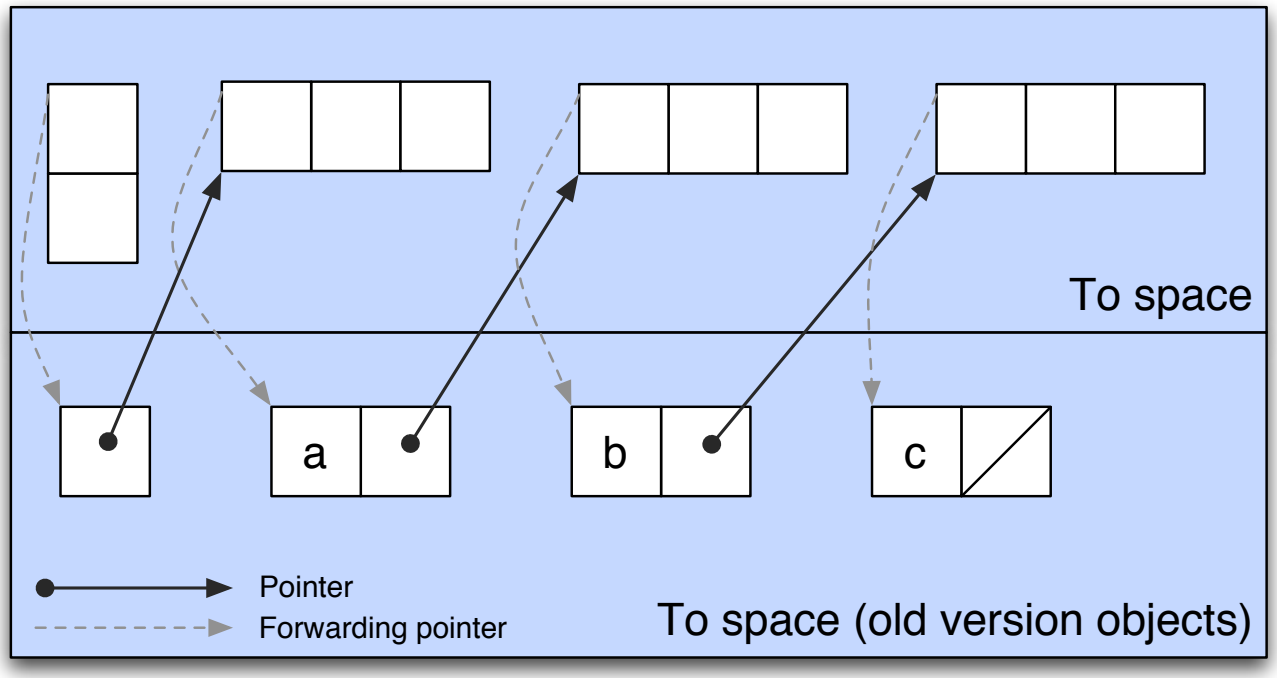
# Singly-linked to doubly-linked list



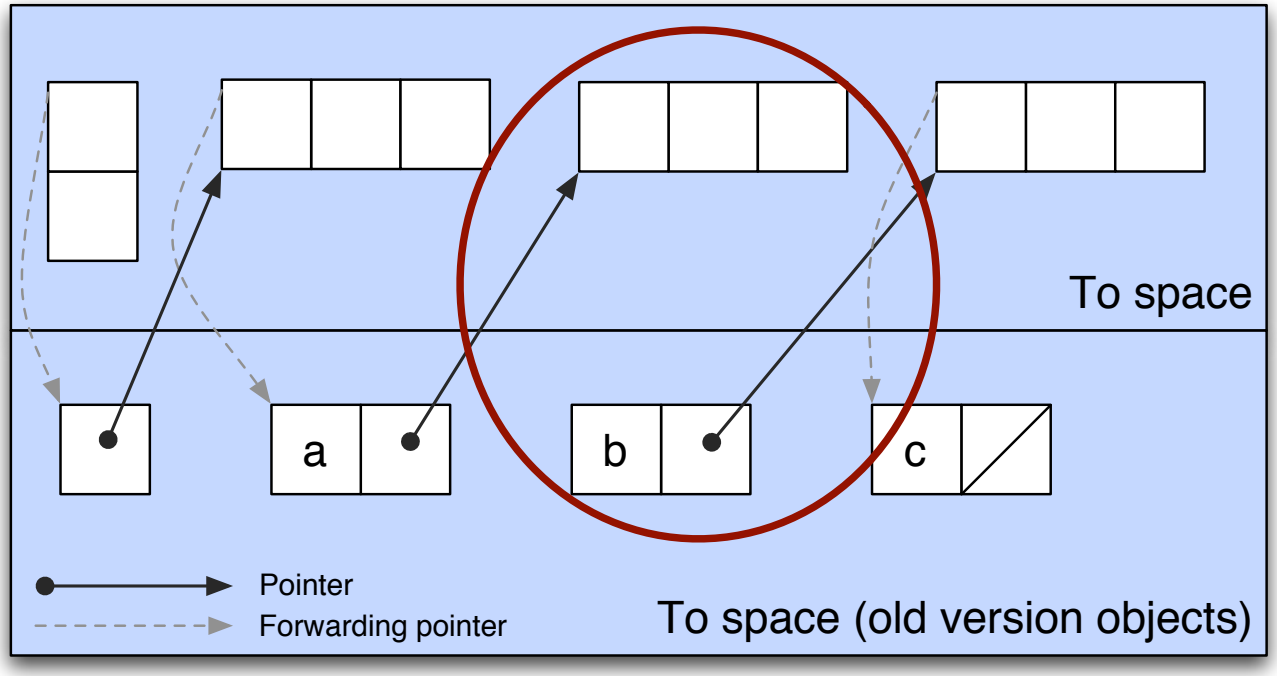
# Singly-linked to doubly-linked list



# Singly-linked to doubly-linked list

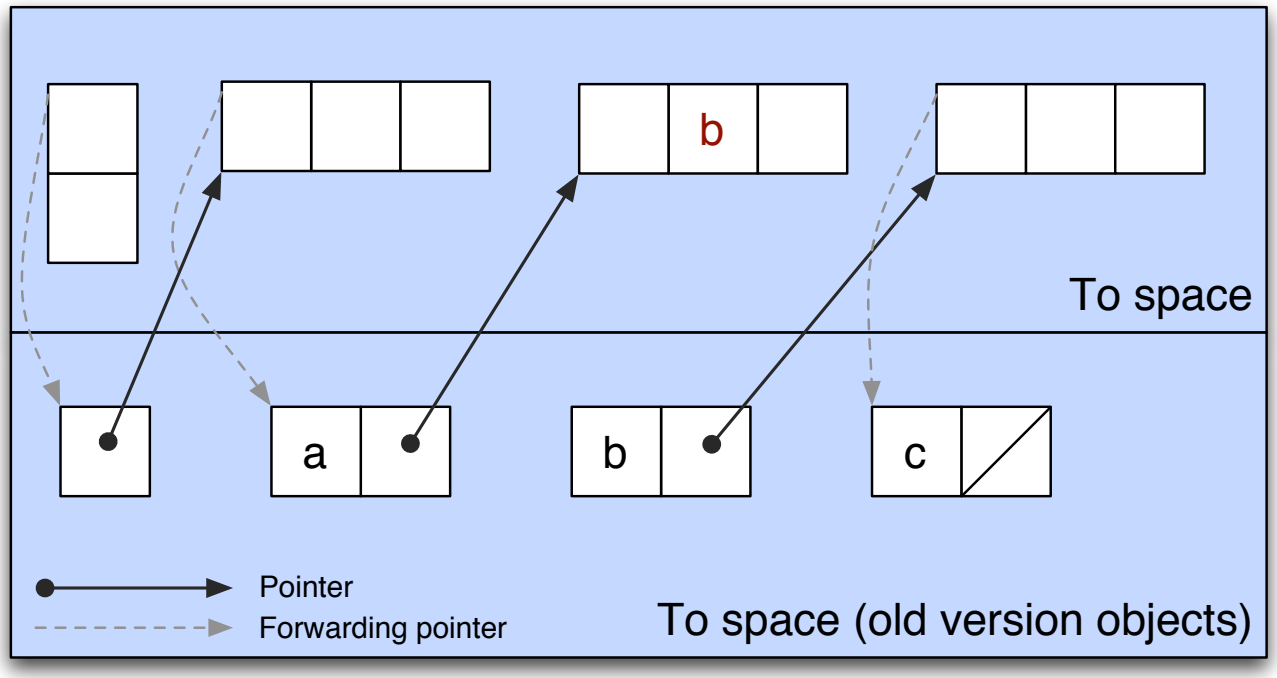


# Singly-linked to doubly-linked list



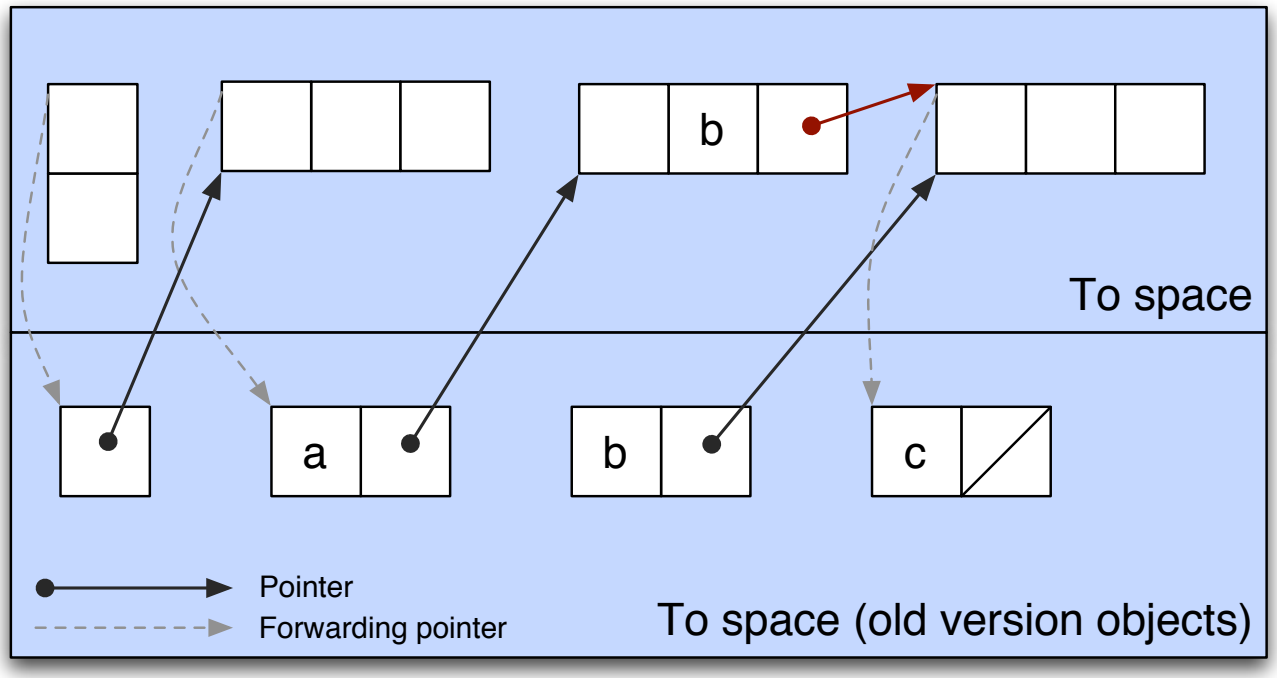

```
jvolveObject(Node to,
    old_Node from) {
  to.data = from.data;
  to.next = from.next;
  if (to.next != null)
    to.next.prev = to;
}
```

# Singly-linked to doubly-linked list



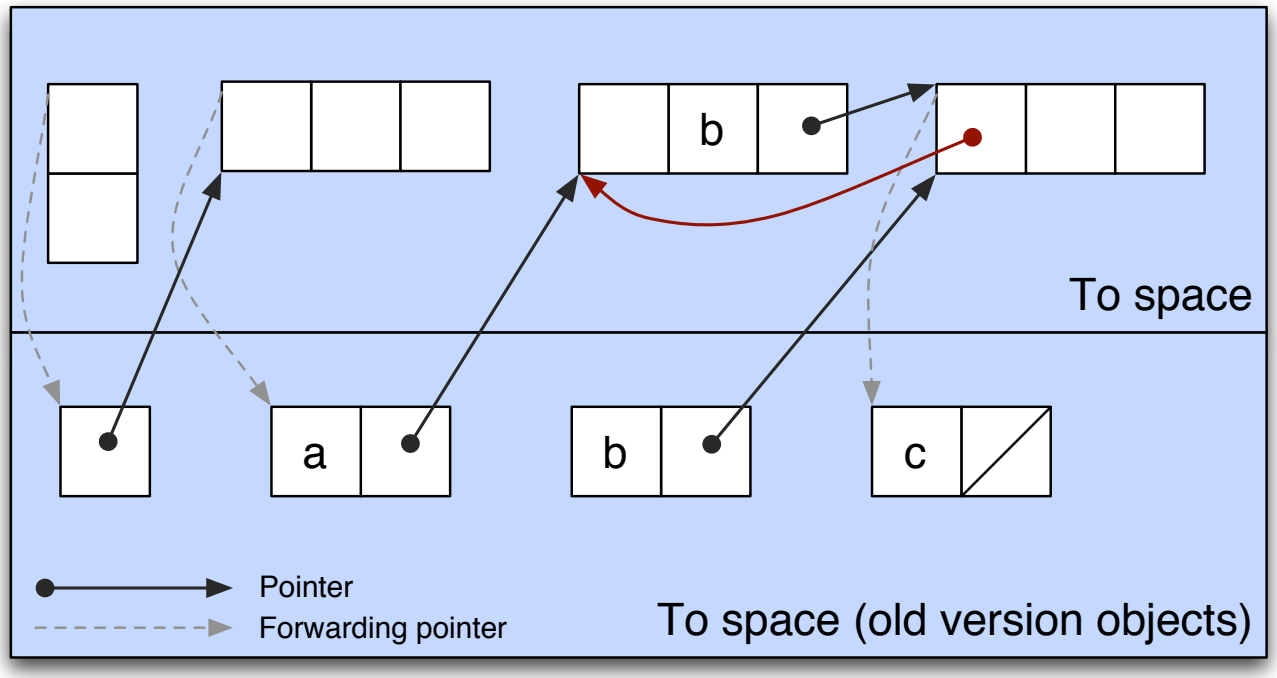

```
jvolveObject(Node to,
    old_Node from) {
  to.data = from.data;
  to.next = from.next;
  if (to.next != null)
    to.next.prev = to;
}
```

# Singly-linked to doubly-linked list



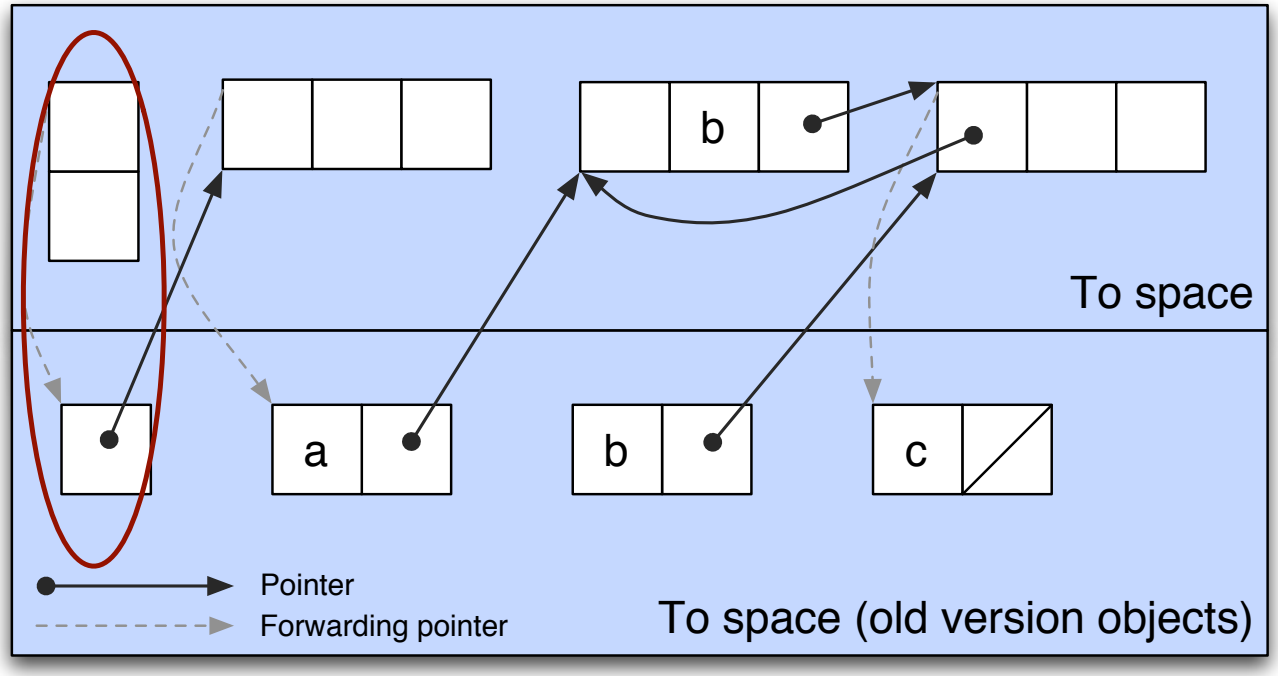

```
jvolveObject(Node to,
     old_Node from) {
  to.data = from.data;
  to.next = from.next;
  if (to.next != null)
    to.next.prev = to;
}
```

# Singly-linked to doubly-linked list

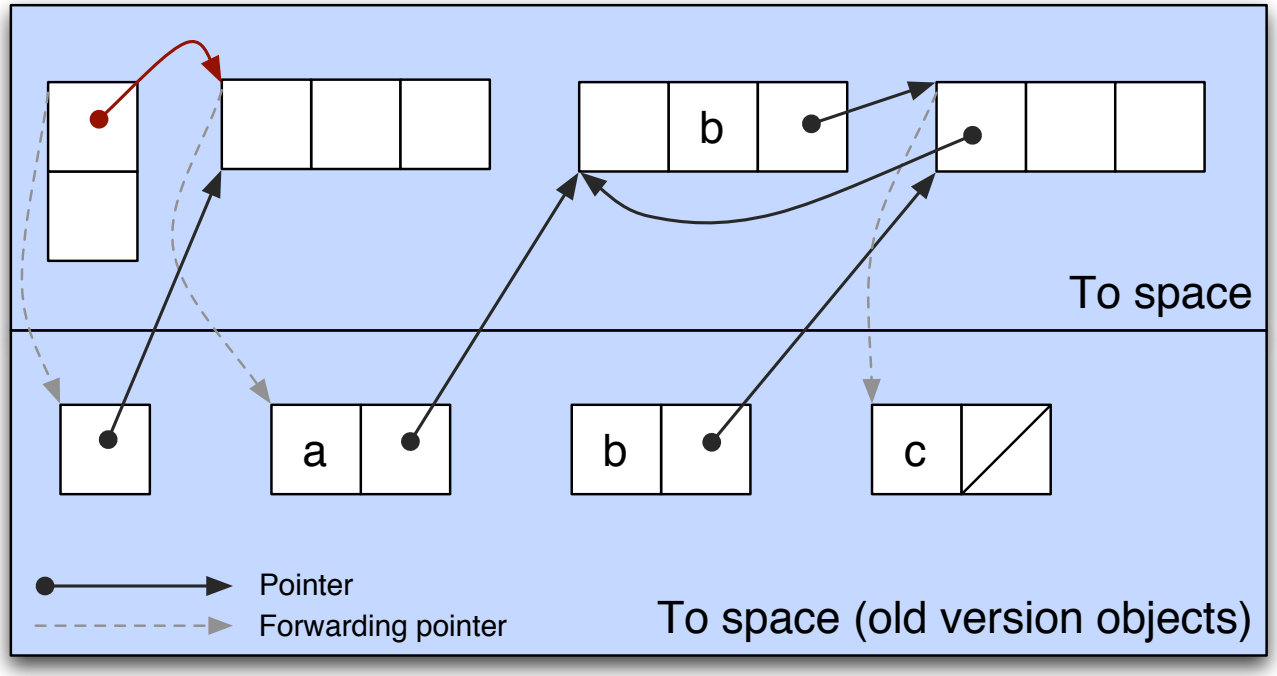



```
jvolveObject(Node to,
     old_Node from) {
  to.data = from.data;
  to.next = from.next;
  if (to.next != null)
    to.next.prev = to;
}
```

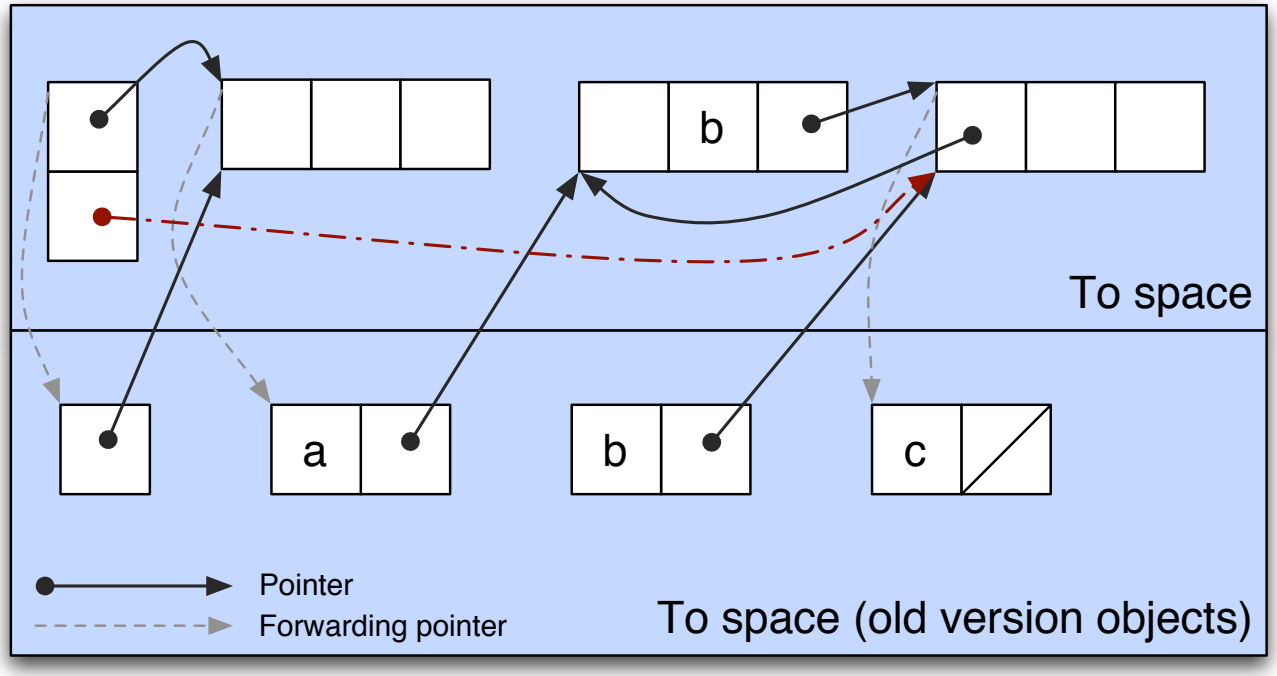
# Singly-linked to doubly-linked list



# Singly-linked to doubly-linked list



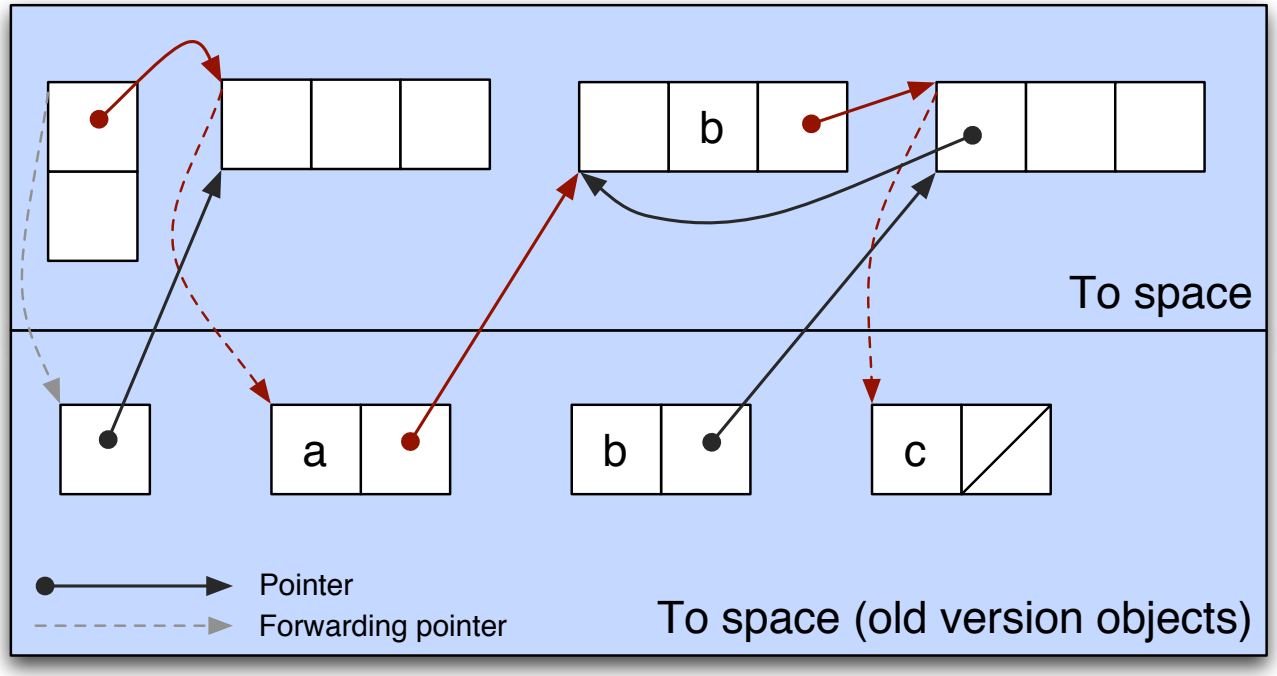
# Singly-linked to doubly-linked list



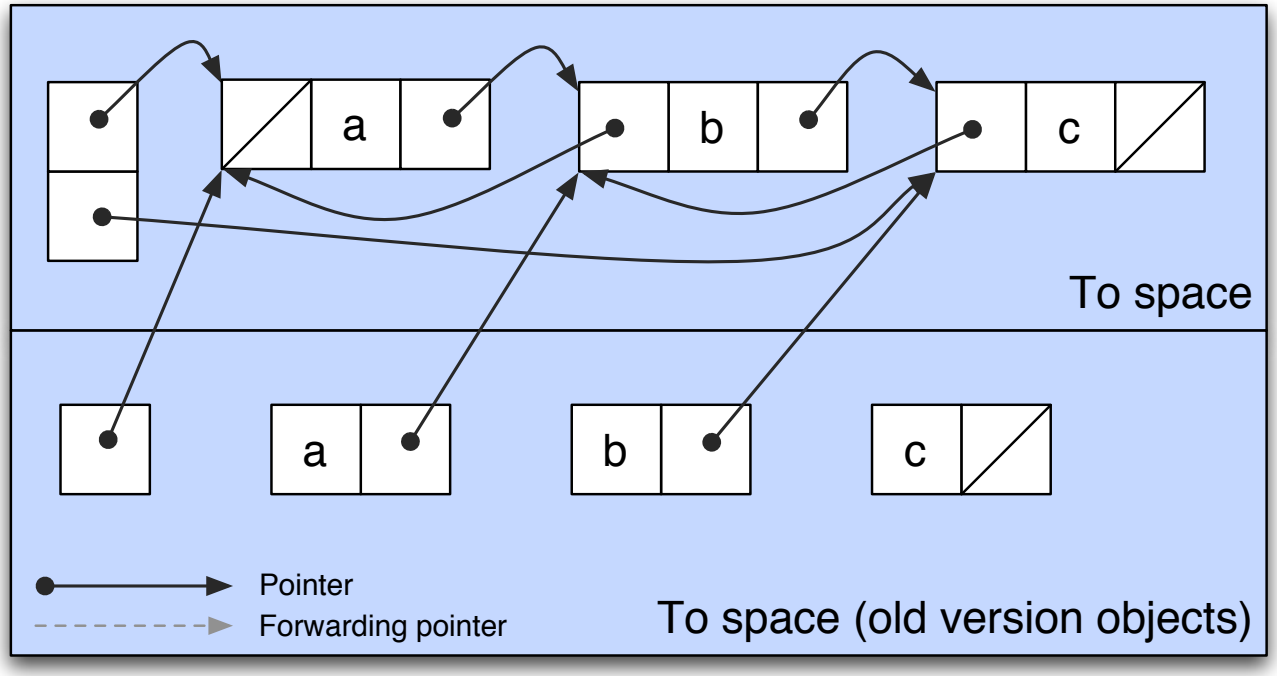
# Finding the list's tail

```
Node prev = null;
Node current = from.head;
while (current != null) {
  prev = current;
  if (! VM.is_transformed(current)) {
    r0_Node current_old = VM.old_version_object(current);
    current = current_old.next;
  } else {
    current = current.next;
  }
}
to.tail = prev;
```

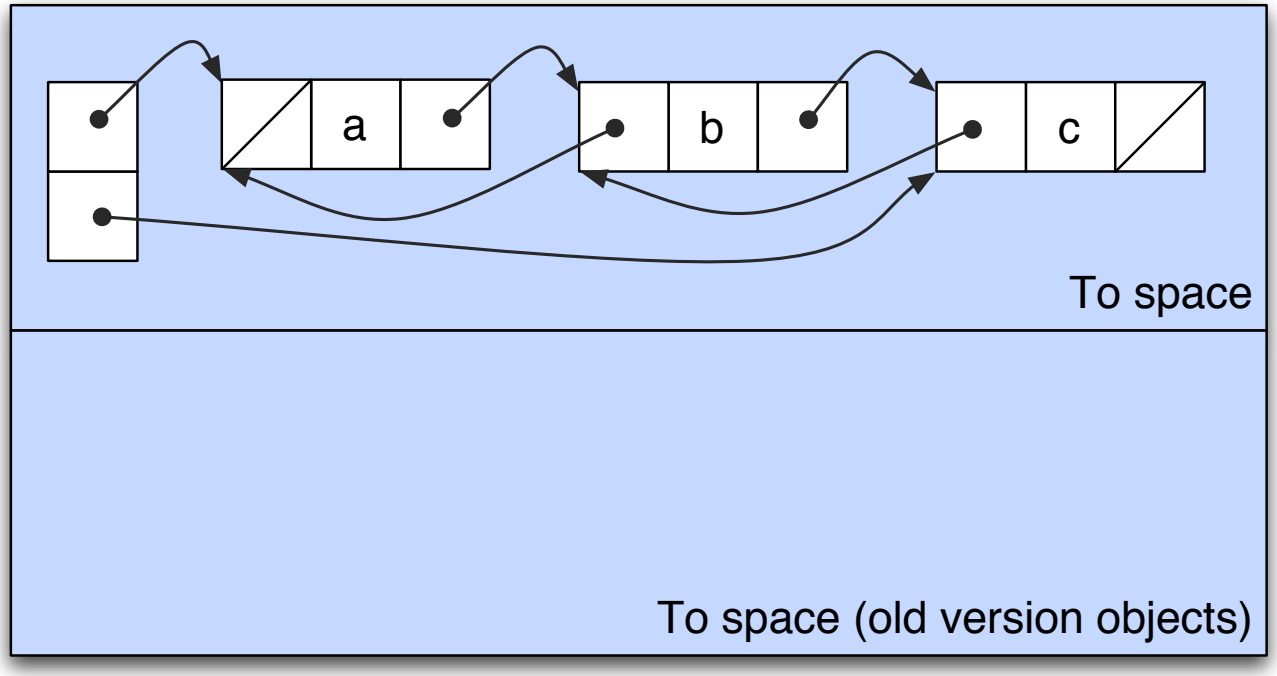
# Singly-linked to doubly-linked list



# Singly-linked to doubly-linked list



# Singly-linked to doubly-linked list



# Outline

- Introduction
- An example of an update
- Update Timing and Safety
- Updating State
  - Object Transformers Model
  - Object Transformers VM Implementation
  - Automating state transformer generation
- Evaluation
- My research vision

# Automating state transformer generation

Goal: Robust, trustworthy handling of simple transformers

- Leave programmer to concentrate on more difficult cases

Approach

- Capture state (ver. 1 and ver. 2) using JVM heap snapshot capability
- Compare states. Matching process produces input/output examples
- Synthesize valid state transformer from the examples

# Azureus memory leak fix

```
1  void
2  transform(PEPeerControlImpl to,
3            old_PEPeerControlImpl from)
4  {
5      if (from.bContinue == false) {
6          to.s.adapter = null;
7      } else {
8          to.s.adapter = from.s.adapter;
9      }
10 }
```

# Outline

# Application Experience

- Jetty webserver
  - 11 versions, 5.1.0 through 5.1.10, 1.5 years
  - 45 KLOC
- JavaEmailServer
  - 10 versions, 1.2.1 through 1.4, 2 years
  - 4 KLOC
- CrossFTP server
  - 4 versions, 1.05 through 1.08, more than a year
  - 18 KLOC

# What works

## Support 20 of 22 updates

- 13 updates change class signature by adding new fields
- Several updates require On-stack replacement support
- Two versions update an infinite loop, postponing the update indefinitely

# Unsupported updates

- JavaEmailServer 1.2.4 to 1.3
  - Update reworks the configuration framework of the server
  - Many classes are modified to refer to the configuration system
  - Including infinite loops in SMTP and POP threads
- Jetty 5.1.2 to 5.1.3
  - The application would never reach a safe point
  - Modified method `ThreadedServer.acceptSocket()` that waits for connections is nearly always on stack
  - Return barrier not sufficient since the main method in other threads `PoolThread.run()` is itself modified

# Outline

- Introduction
- An example of an update
- Update Timing and Safety
- Updating State
  - Object Transformers Model
  - Object Transformers VM Implementation
  - Automating state transformer generation
- Evaluation
- My research vision

# Make web-applications better

- Seamlessly distribute computing between client/proxy/server
  - Adaptively move compute to offer best user(s) experience
  - Customized solutions exist
    - Amazon Silk runs part of the browser on the cloud
    - Netflix video codec variation by device/bandwith
- Going from prototype to scale
  - Producity always wins over performance
  - PHP, Python, and Ruby have won the productivity war
  - Performance comes later: Twitter moves to Scala, Facebook compiles PHP
  - Establish JVM as the instruction set of webapps?

# Conclusion

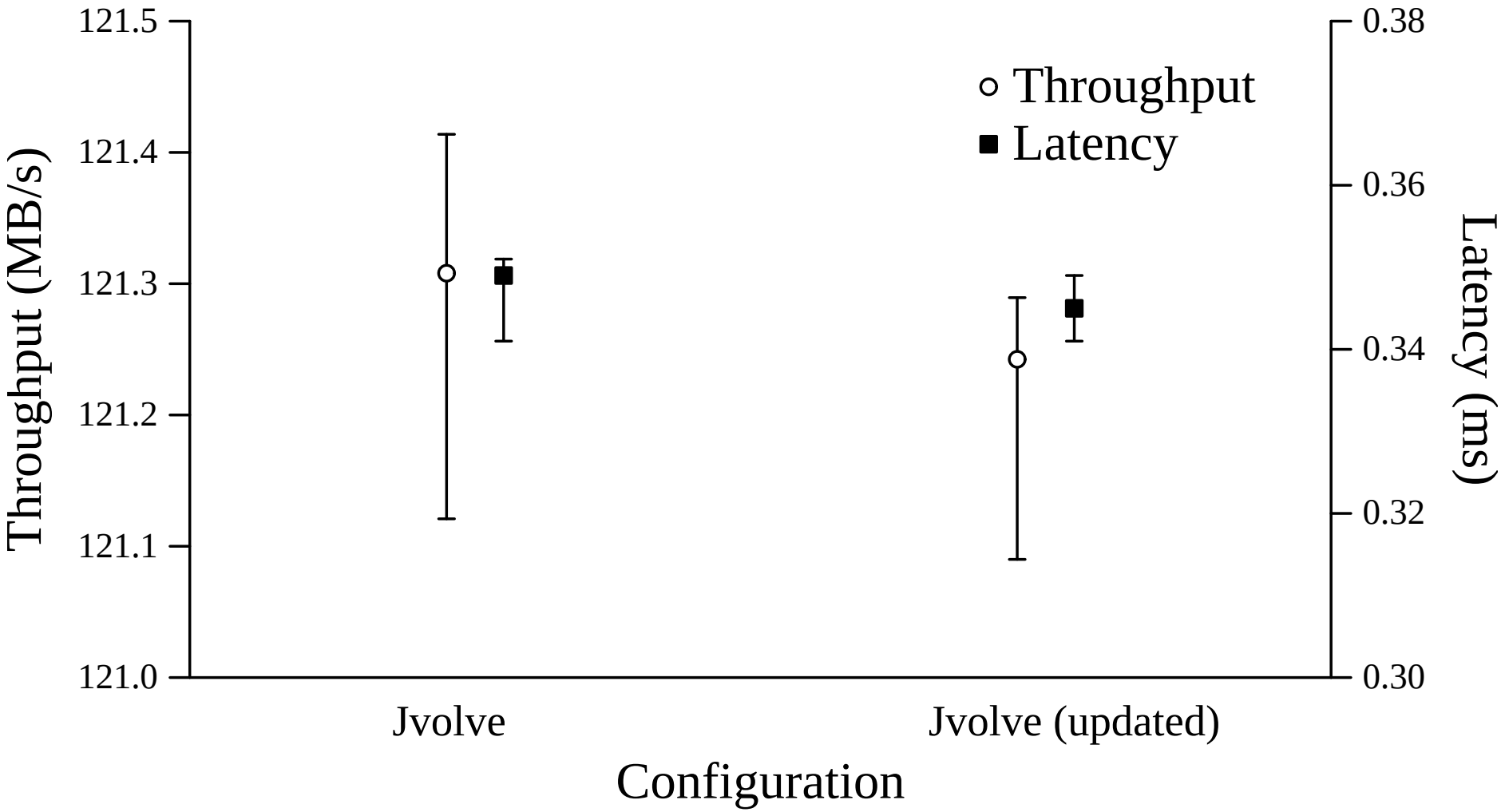
- JVOLVE, a Java VM with support for Dynamic Software Updating
- Most-featured, best-performing DSU system for Java
- Naturally extends existing VM services
- Supports about two years worth of updates

*Dynamic software updating in managed languages can be achieved in a safe, flexible and efficient manner.*

# Backup slides

# JVOLVE performance

## No overhead during steady-state execution



# Jetty webserver performance

- Used `httperf` to issue requests
- Both client and server on a the same machine, an Intel Core 2 Quad
- Report throughput and latency, median of 21 runs

# DSU pause times

- JVOLVE performs a GC to transform objects
- Pause time determined by
  - Heap size
  - # of objects transformed
- Simple microbenchmark varying the fraction of objects transformed in a 1GB heap

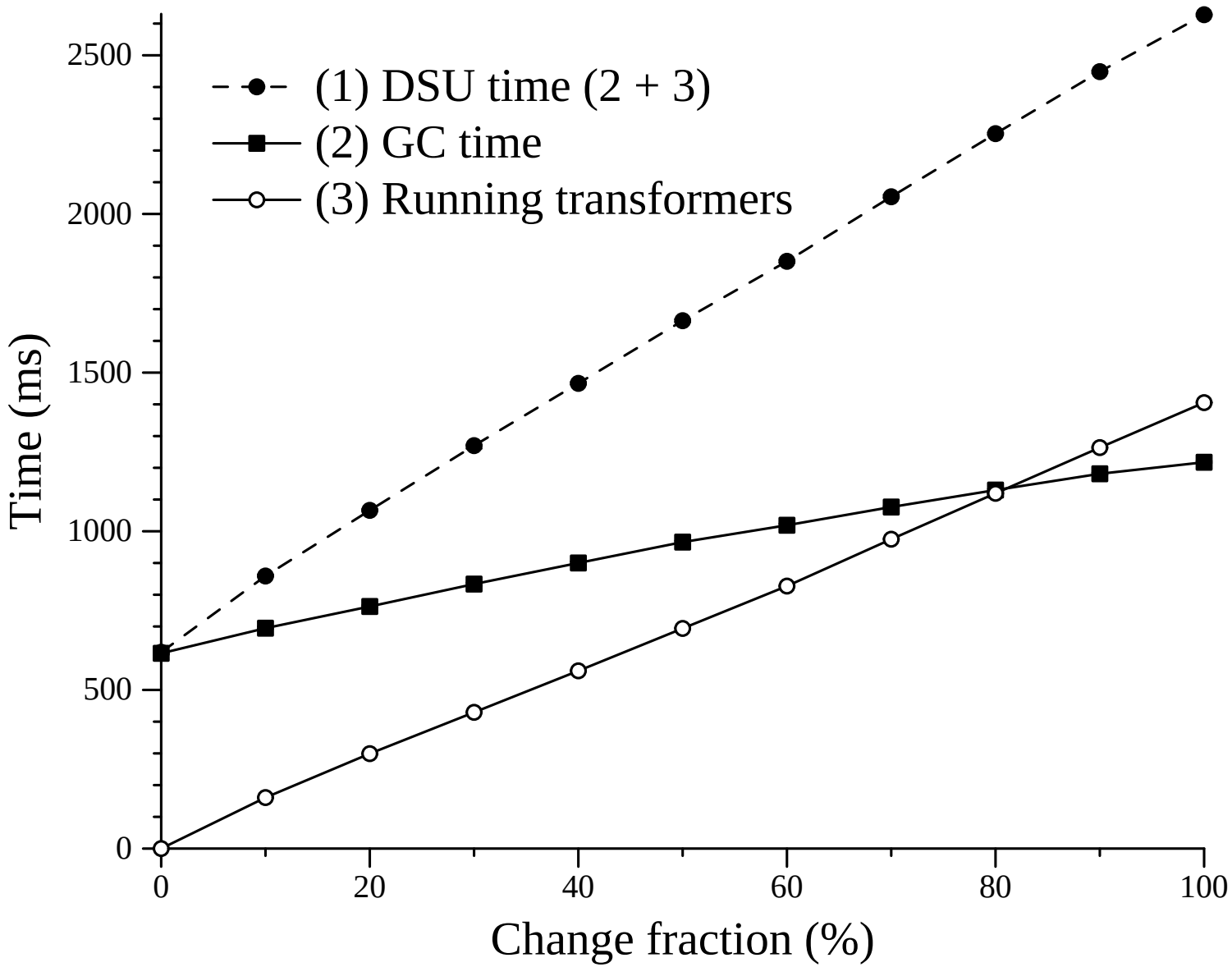
# Update pause time

- No apriori overhead during normal execution (before and after the update)
- Only effect on execution time is the update pause time
  - Comparable to GC pause time

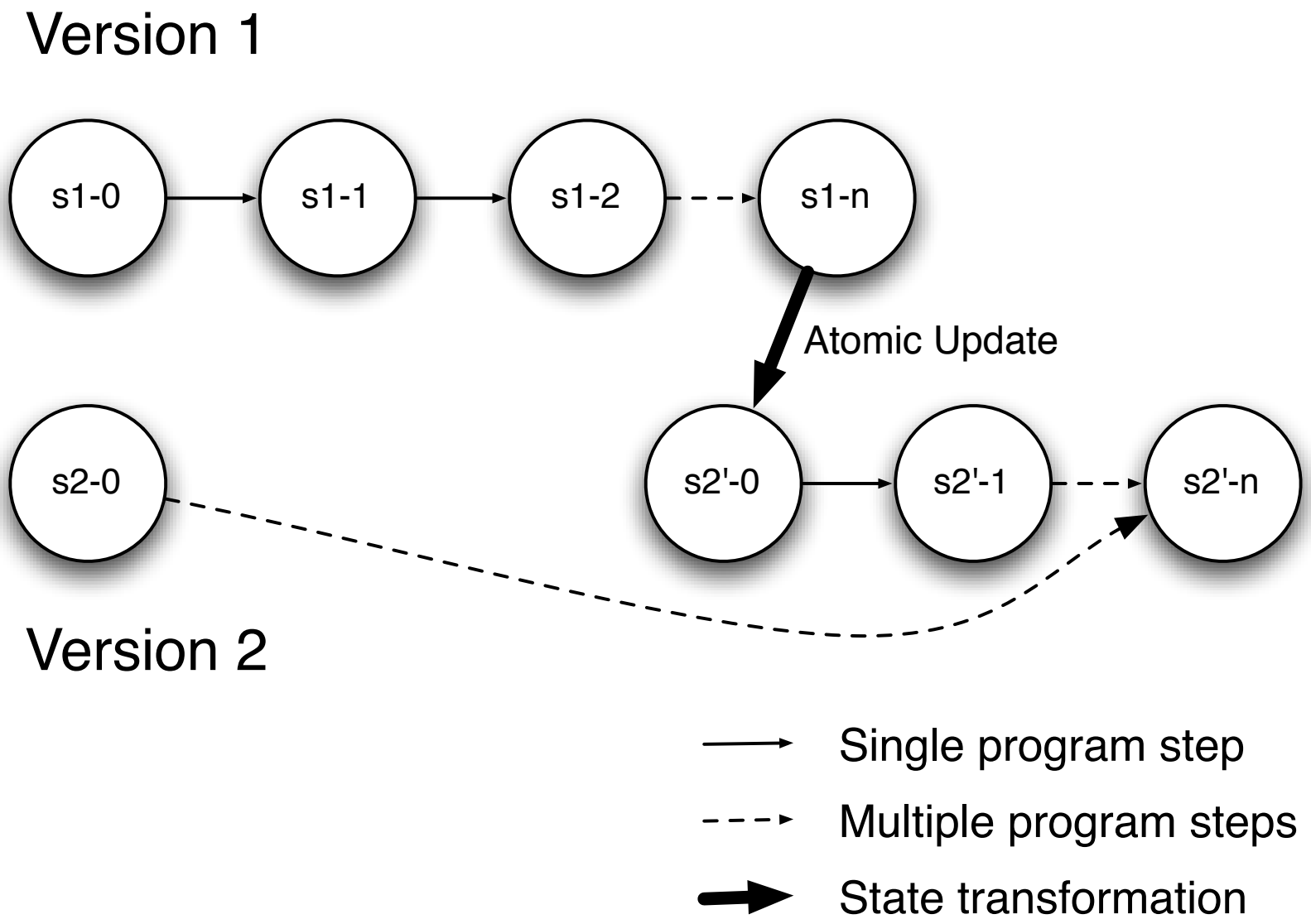
# Update pause time

$$
\begin{aligned}
\text{DSU Pause Time} \;&\approxeq\; \text{Regular GC Time} + \\
&\qquad \text{Time to allocate upd. objects} + \\
&\qquad \text{Time to transform objects} \\
&\propto\; \text{Upd. objects fraction} \\
&\qquad \text{Heap size}
\end{aligned}
$$

# DSU pause times (microbenchmark)



# Update correctness



# Correct update semantics

Update correctness depends on semantics of application and state transformers

- Transformer that initializes all variables to "unknown" is equivalent to restarting the program. Not useful.
- When going from an 8-bit to 16-bit counter, no correct transformer exists

# Safety Guarantees

- Correctness
  - Showing an update correct is undecidable
  - Rely on programmer and testing process for semantics and safety of update
- Well-formed updates
  - All data accesses and method calls in the program respect language semantics.
  - Type safety