Dynamic Software Updates: A VM-centric Approach

Suriya Subramanian[1] Michael Hicks[2]
Kathryn S. McKinley[1]

[1]Department of Computer Sciences
The University of Texas at Austin

[2]Department of Computer Science
University of Maryland, College Park

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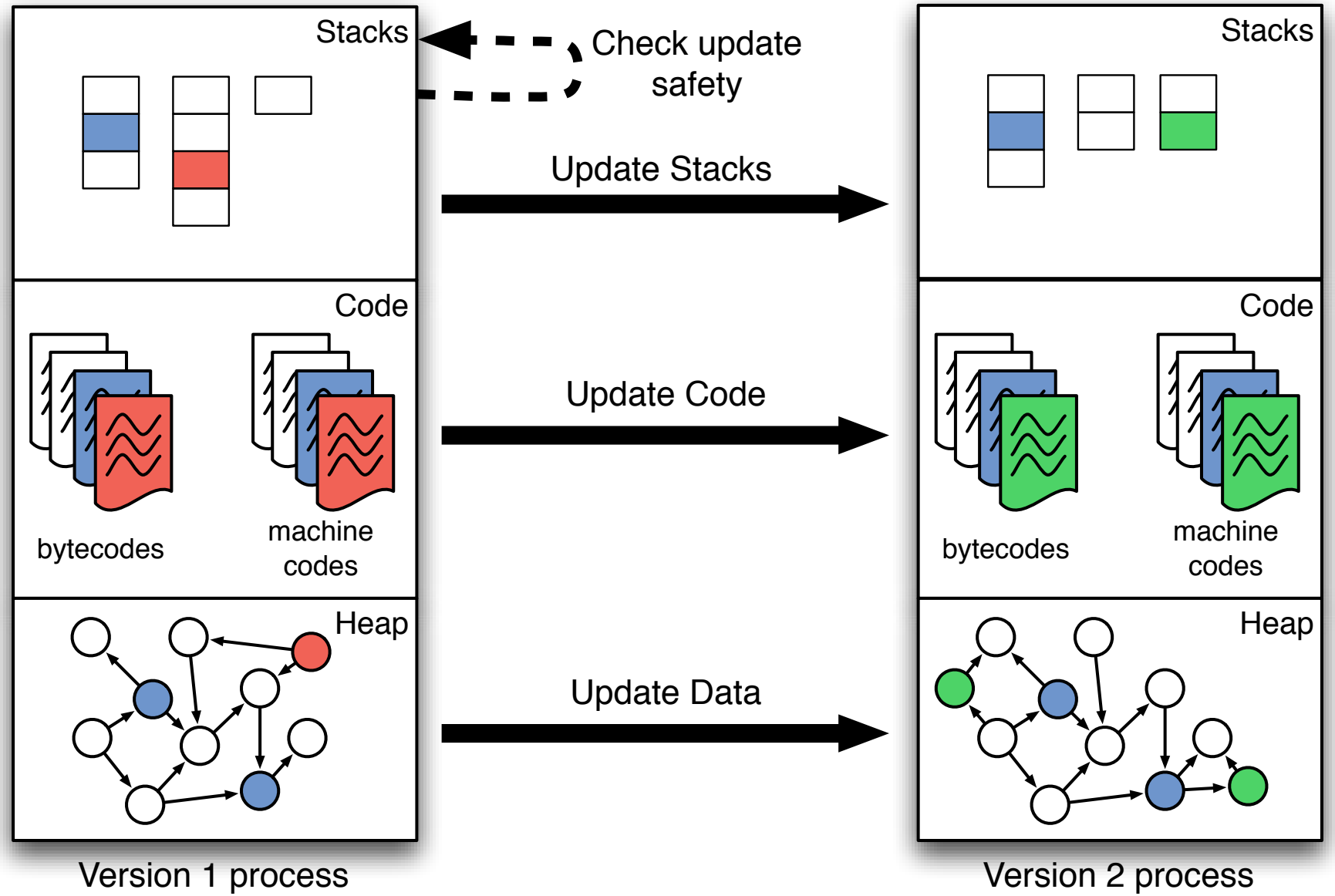
Motivation

- Software applications change all the time
- Deployed systems must be updated with bug fixes, new features
- Updating typically involves: stop, apply patch, restart
- Not desirable
  - Safety concerns
  - Revenue loss
  - Inconvenience

Dynamic software updating



Dynamic updating systems

- Special-purpose architectures, application-specific solutions exist
- General-purpose solutions gaining strength
  - K42, Ksplice for OS updates
  - Polus, Ginseng for C applications
- Not for managed languages

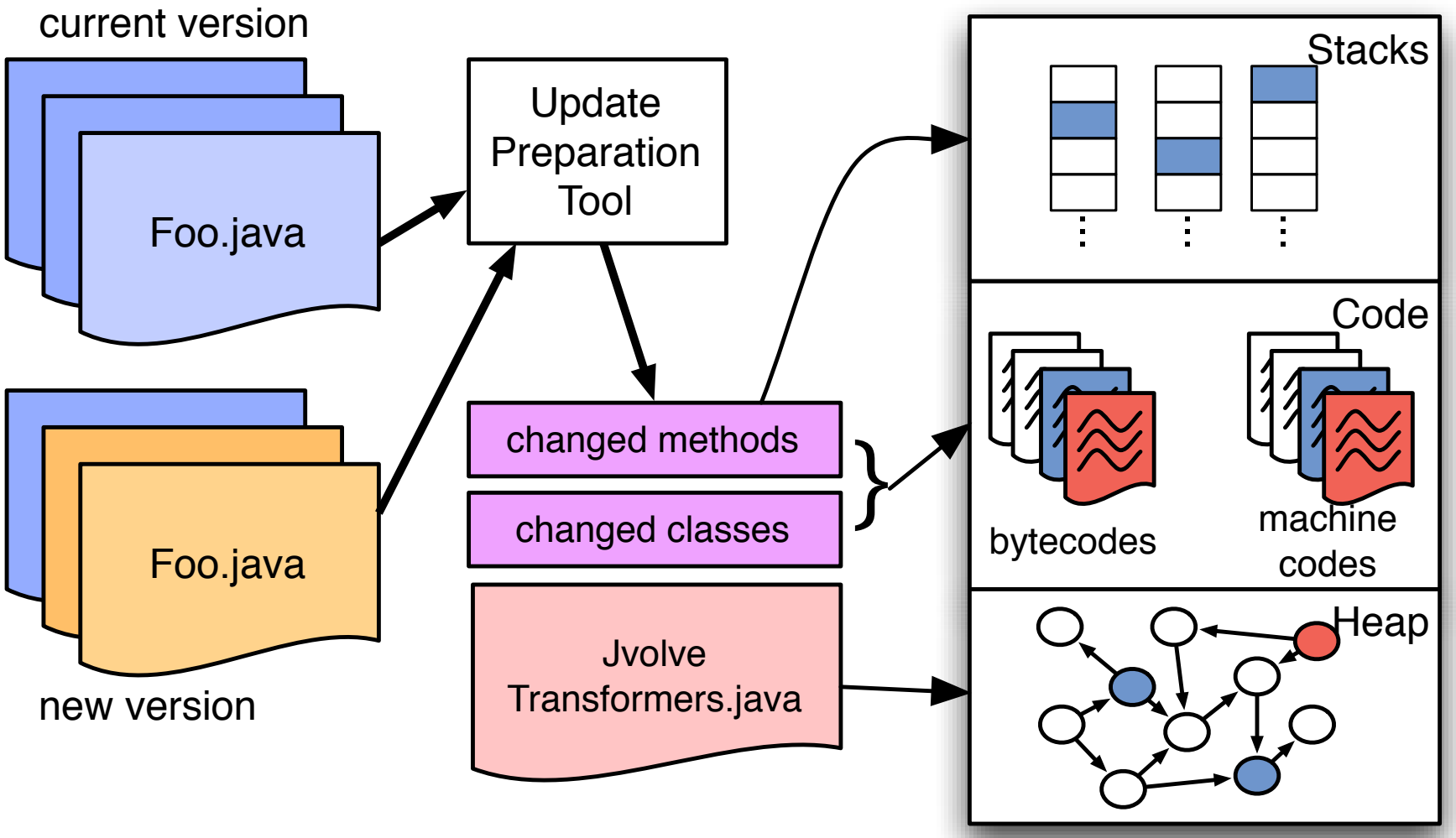
Our solution

- JVOLVE - a Java Virtual Machine with DSU support
- Key insight: Extend existing VM services
- No DSU-related overhead during normal execution
- Support updates to real world applications

Dynamic software updating in managed languages can be achieved in a **safe**, **flexible** *and* **efficient** *manner by naturally extending existing VM services.*

DSU support should be a standard feature of future VMs.

JVOLVE - System overview



Supported updates

- Changes within the body of a method

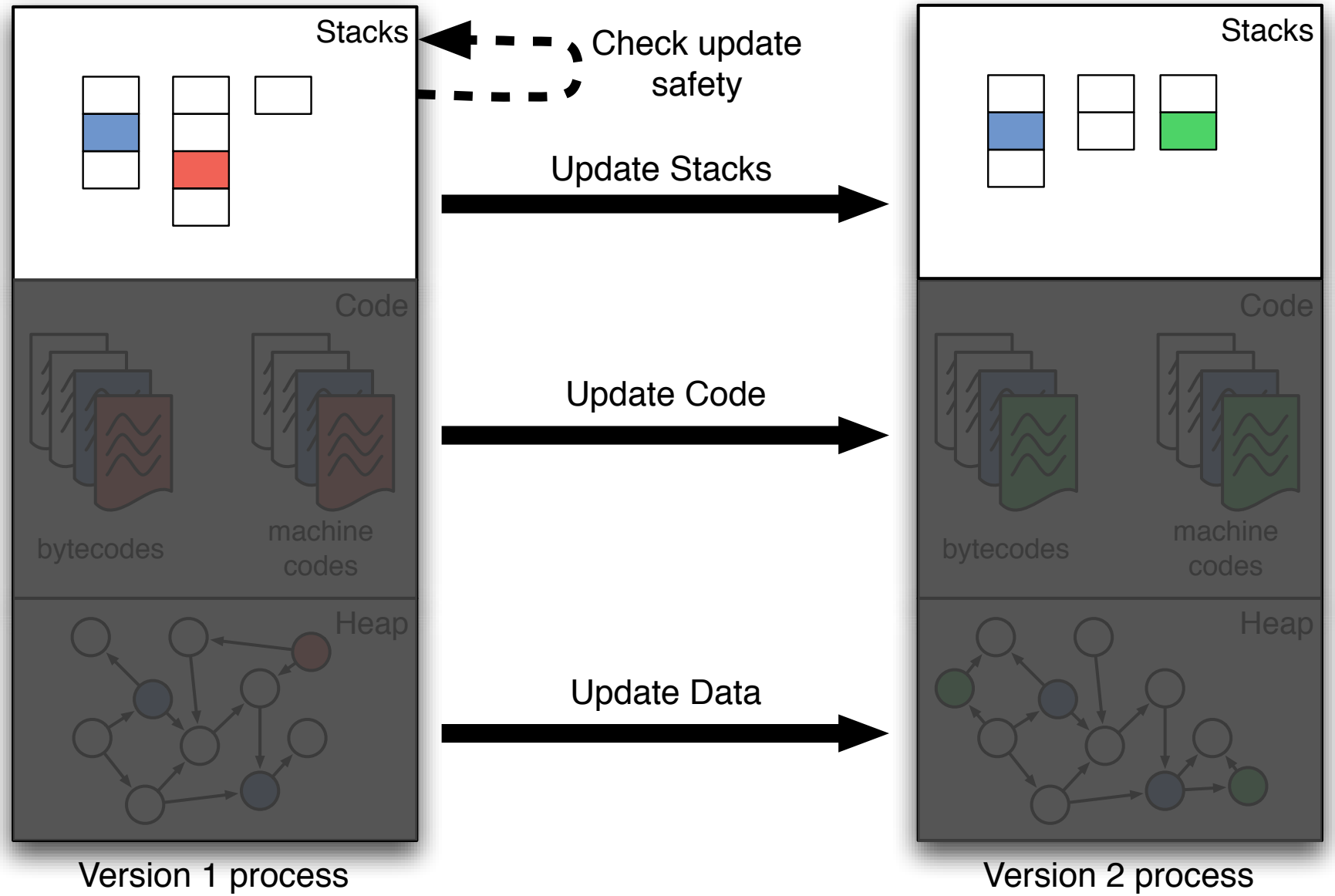
```
  public static void main(String args[]) {
    System.out.println("Hello, World.");
+   System.out.println("Hello again, World.");
  }
```

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

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

- Signature updates require an object transformer function

Check for update safety



Safe point for the update

- Update must be atomic
- 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

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

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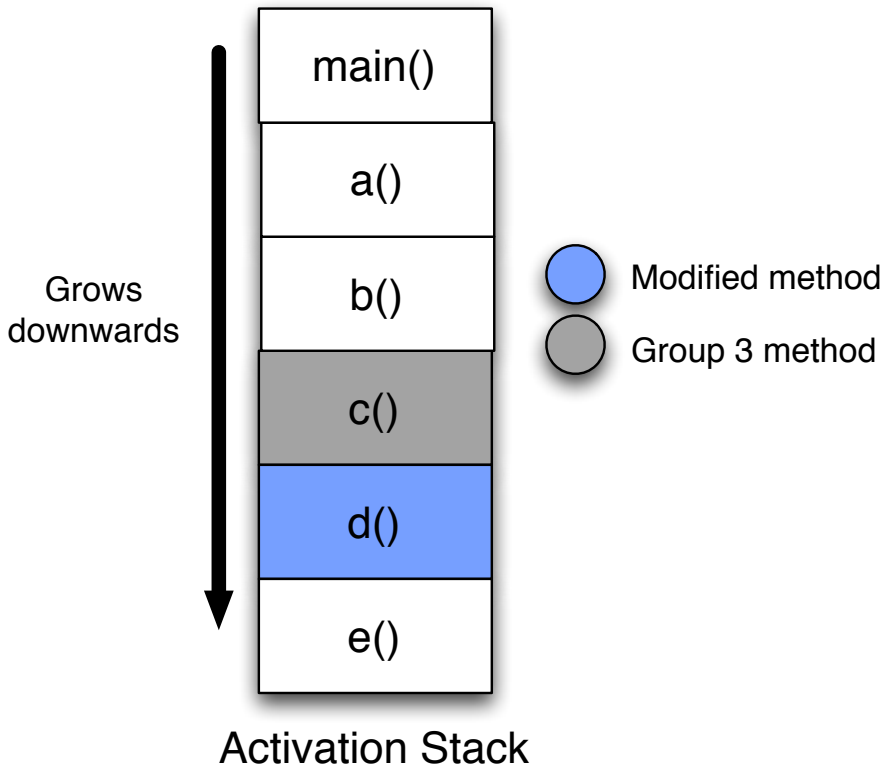
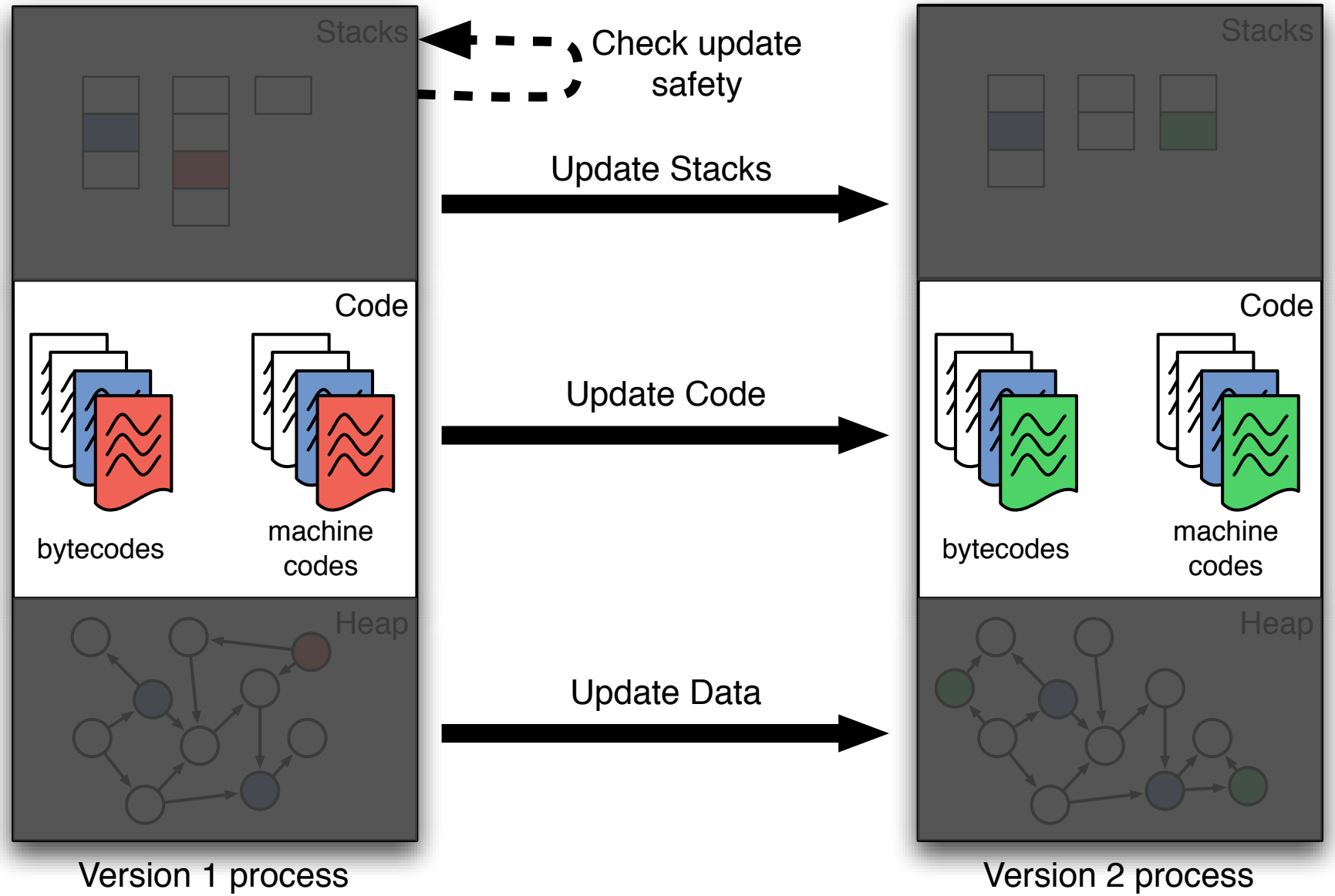
Reaching a safe point



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

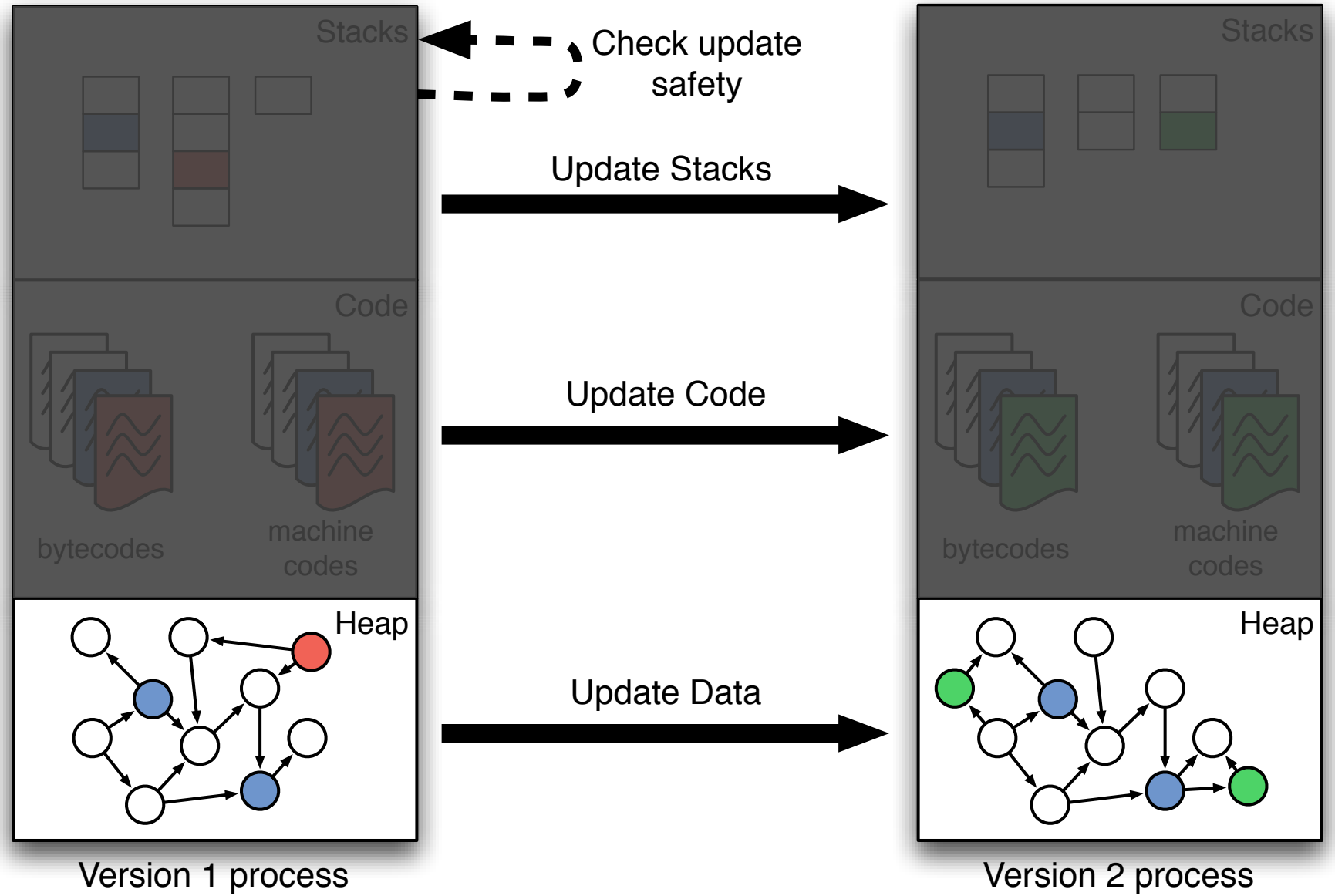
Update code


Stacks
Check update safety
Update Stacks
Code
bytecodes
machine codes
Update Code
Heap
Update Data
Version 1 process
Stacks
Code
bytecodes
machine codes
Heap
Version 2 process

Update code

- Modify class loader to recognize new versions of classes
- Install new versions of classes and methods
- Rely on Just-in-time Compiler to compile new versions of methods on demand
- Extend On-stack replacement to update active methods

Update data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Version 2 process

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;
    }
  }
```

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    public User(...) {...}
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-       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] =
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}}}
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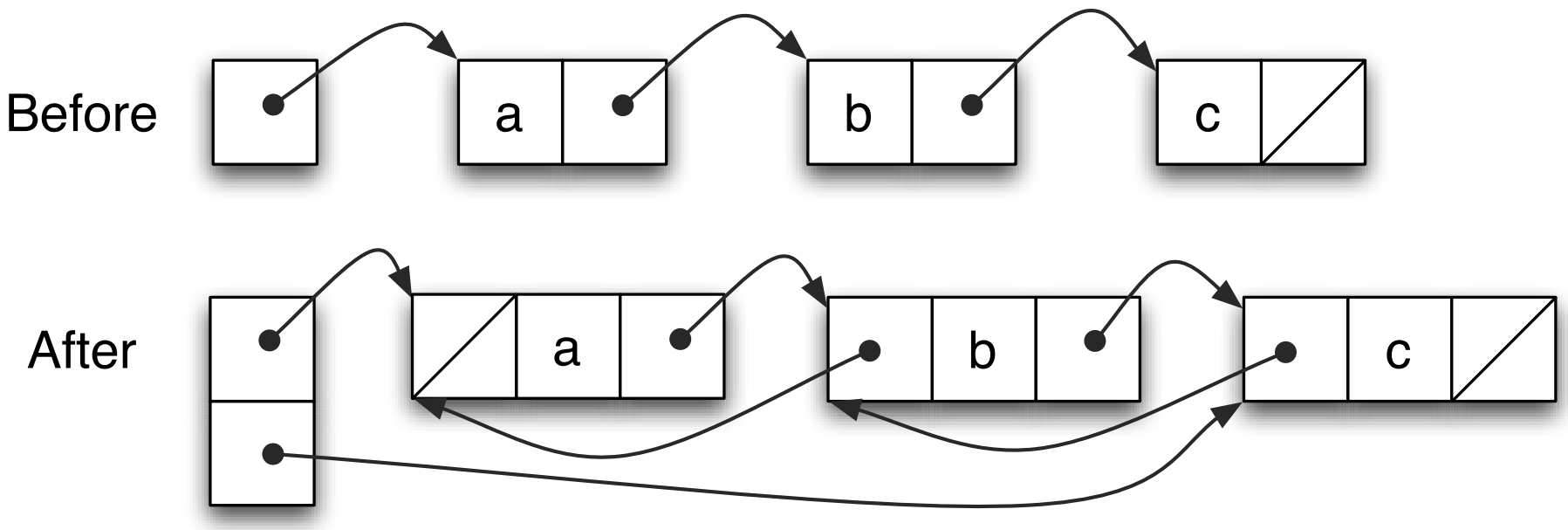
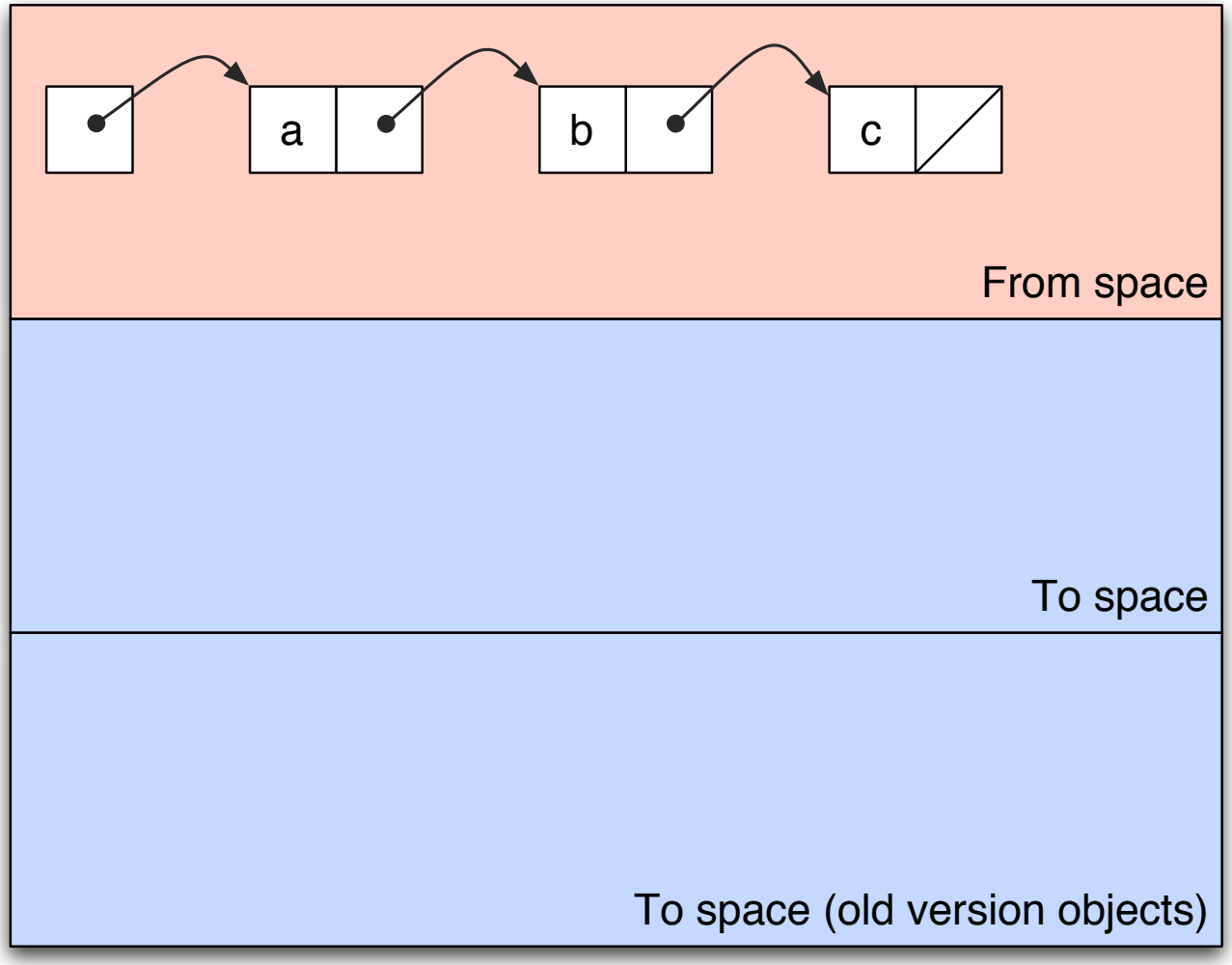
Transforming objects in the GC



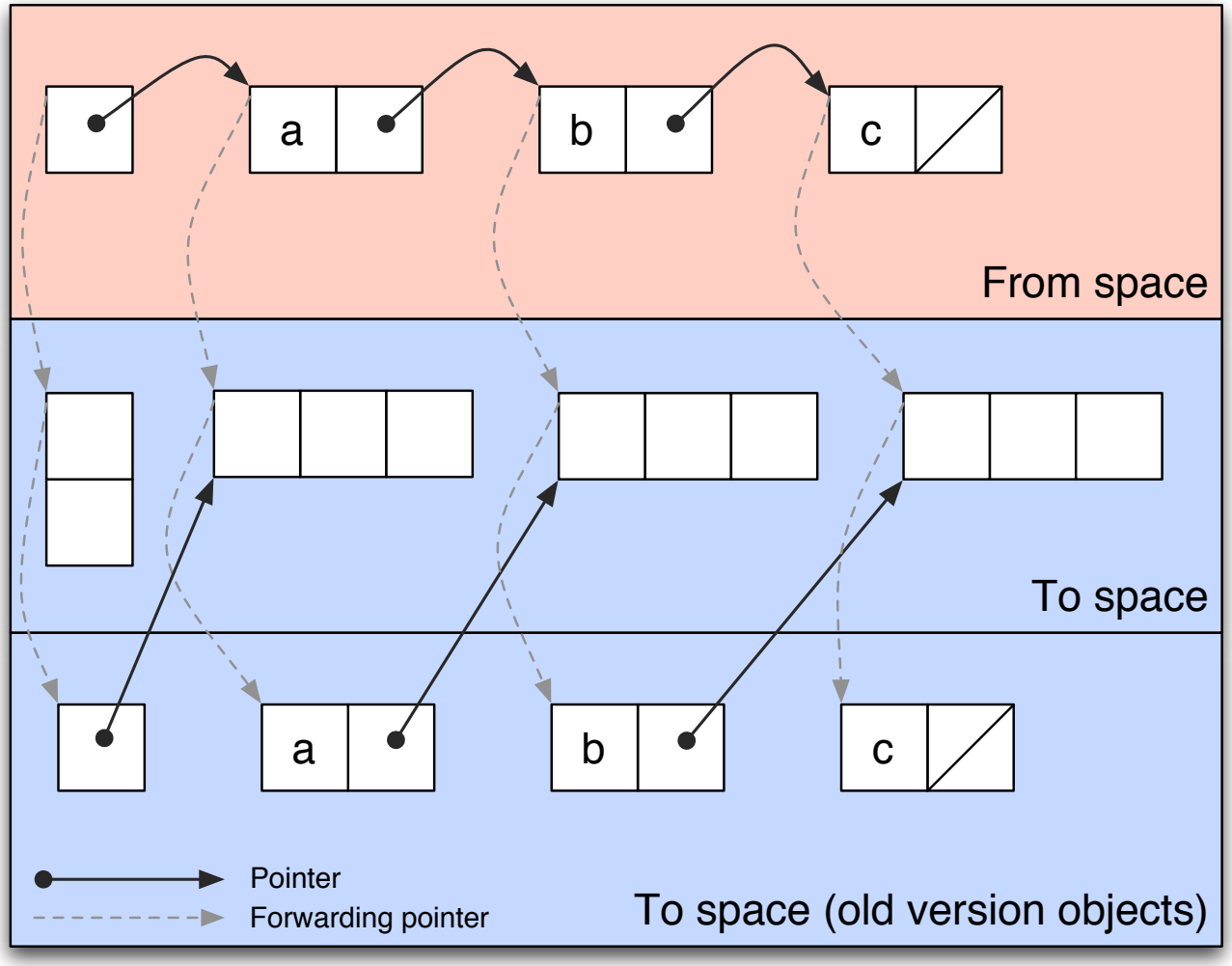
Happens in two steps

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

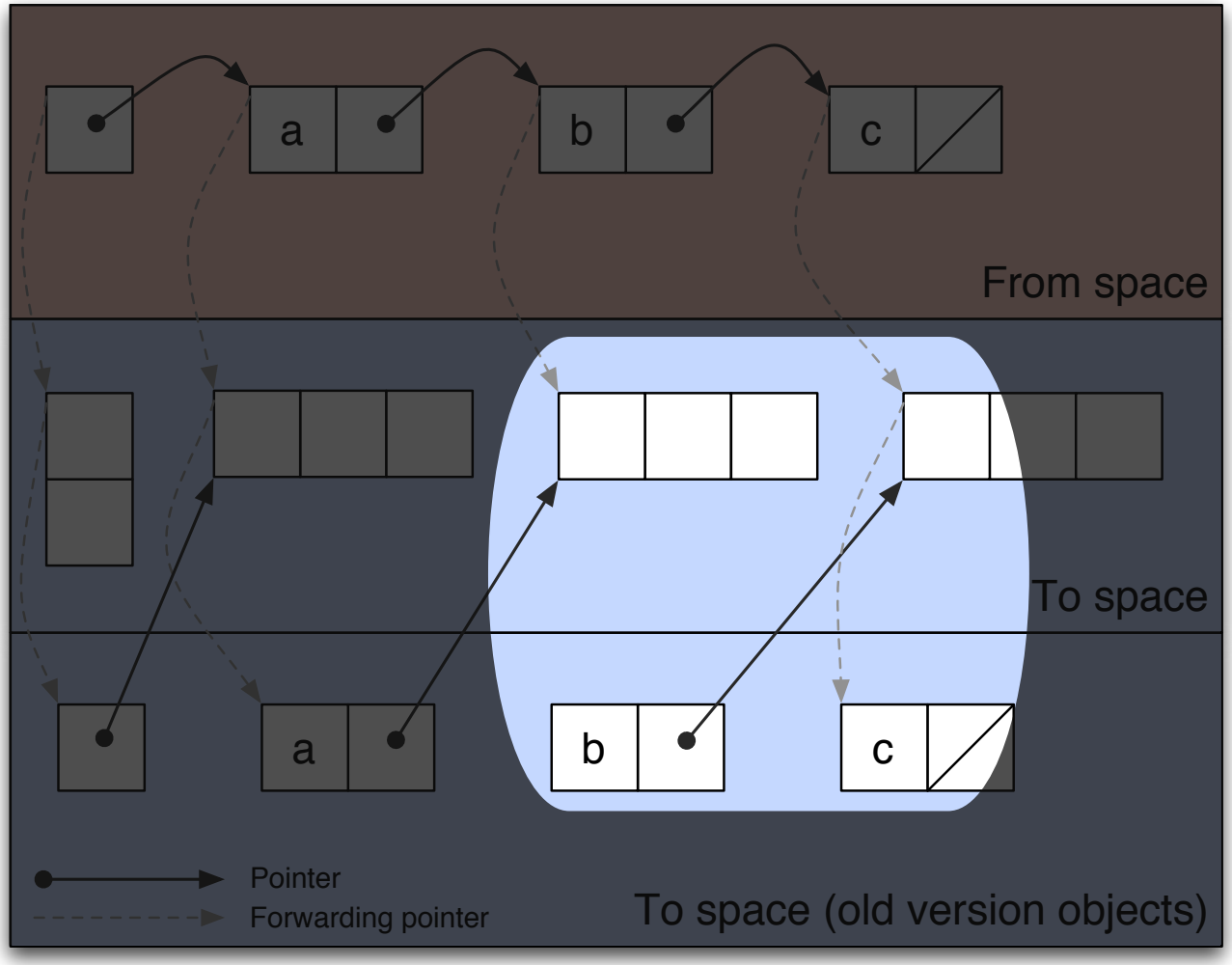
Jvolve GC



Jvolve GC

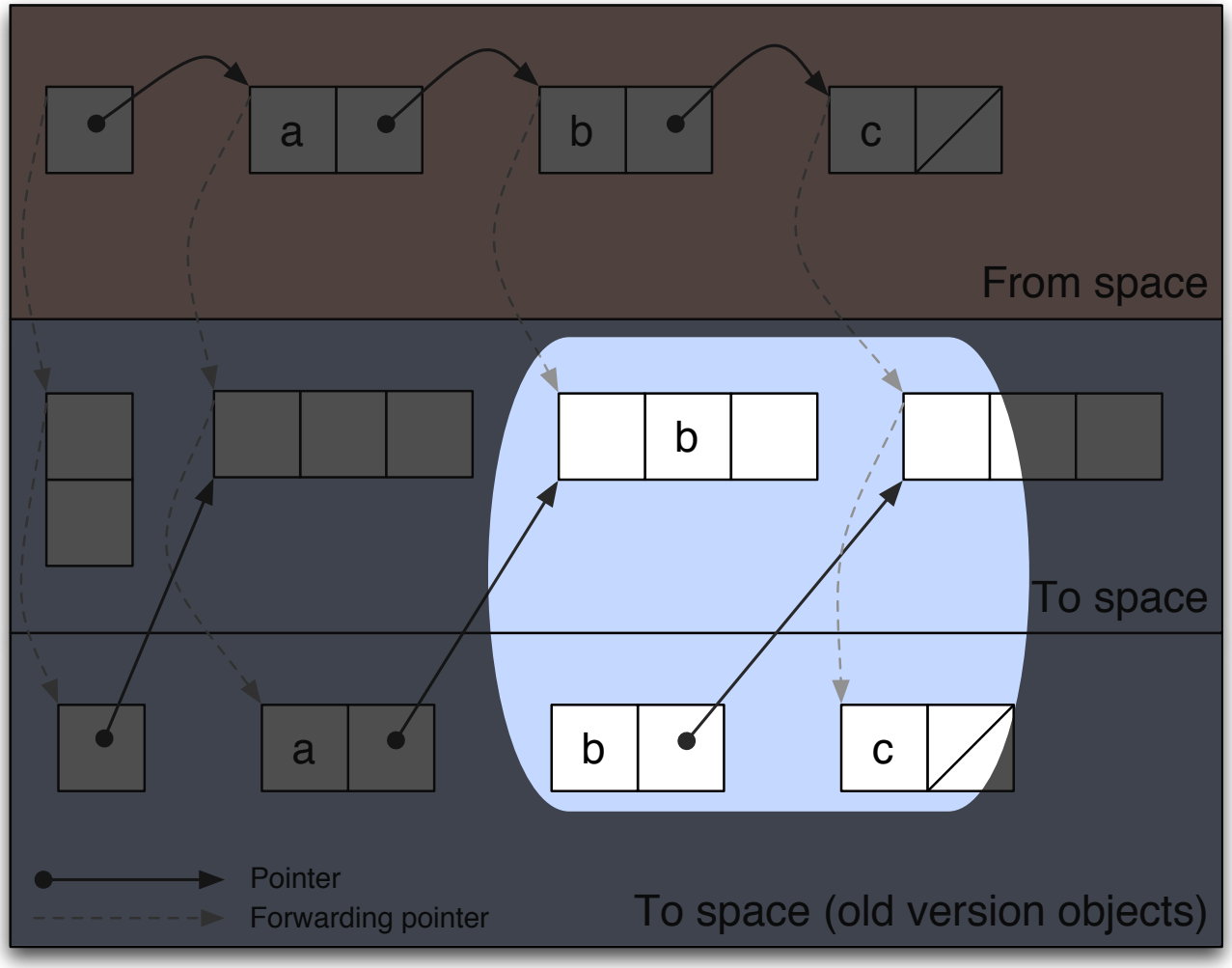

a
b
c
From space
To space
a
b
c
Pointer
Forwarding pointer
To space (old version objects)

Jvolve GC




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

Jvolve GC

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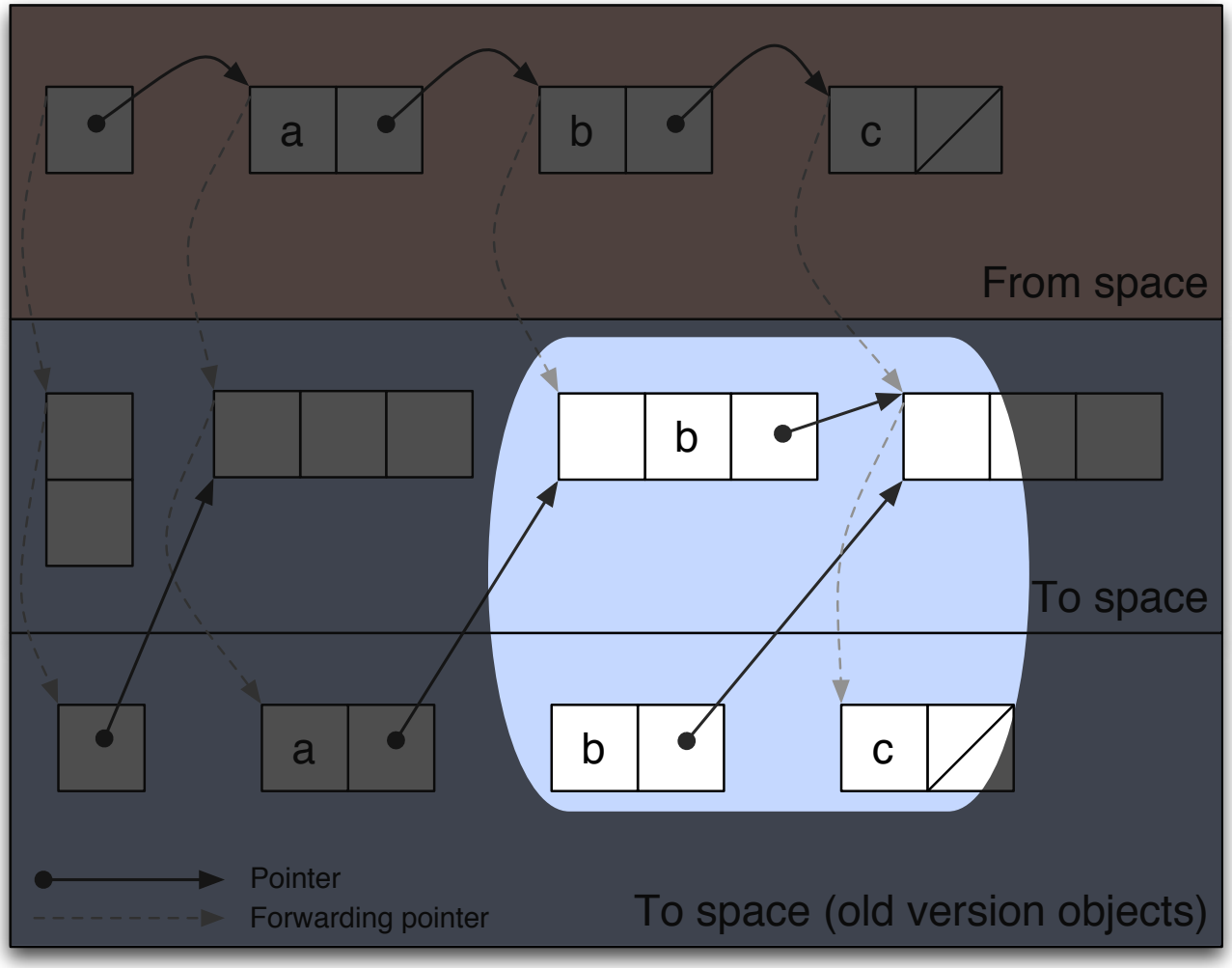


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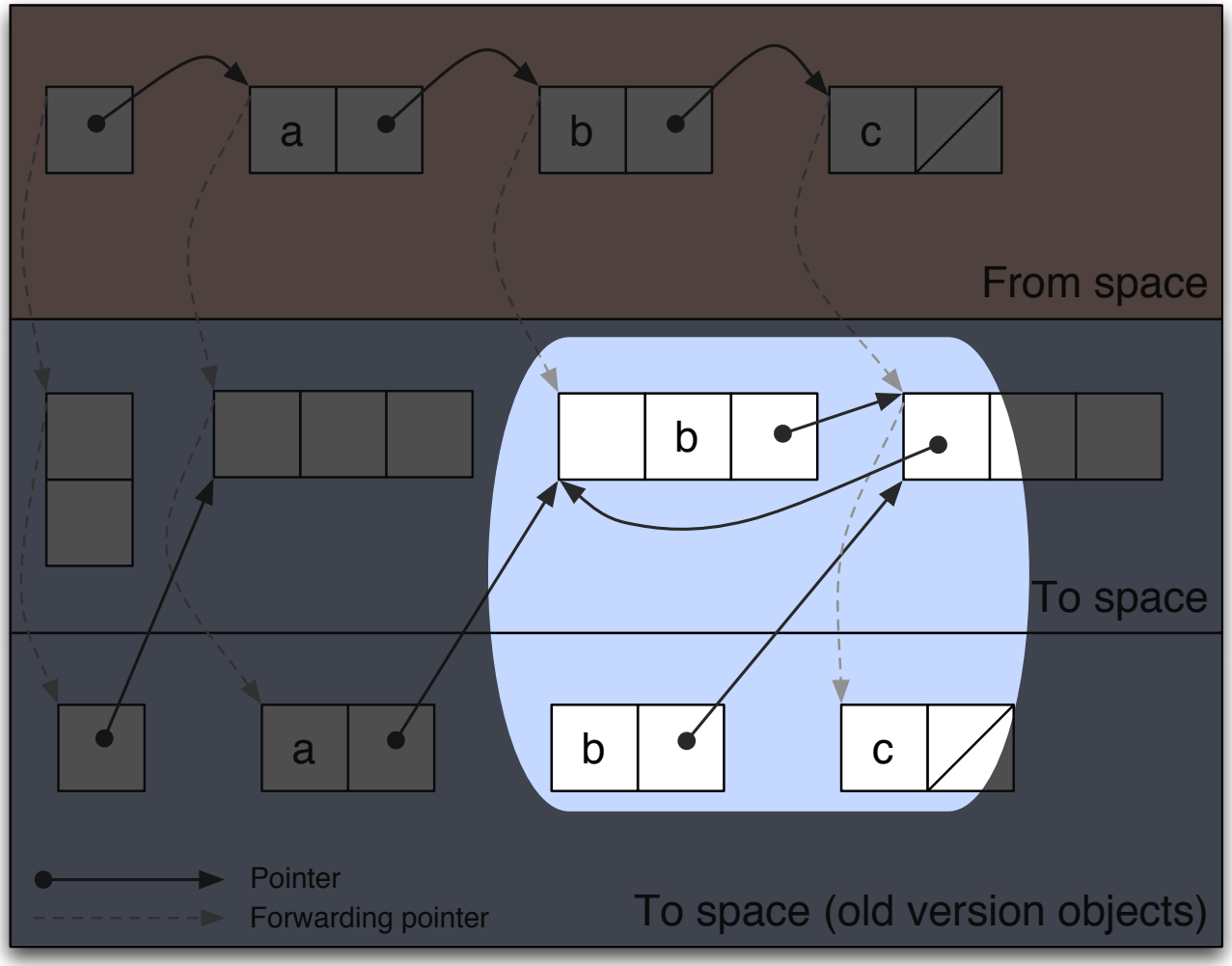


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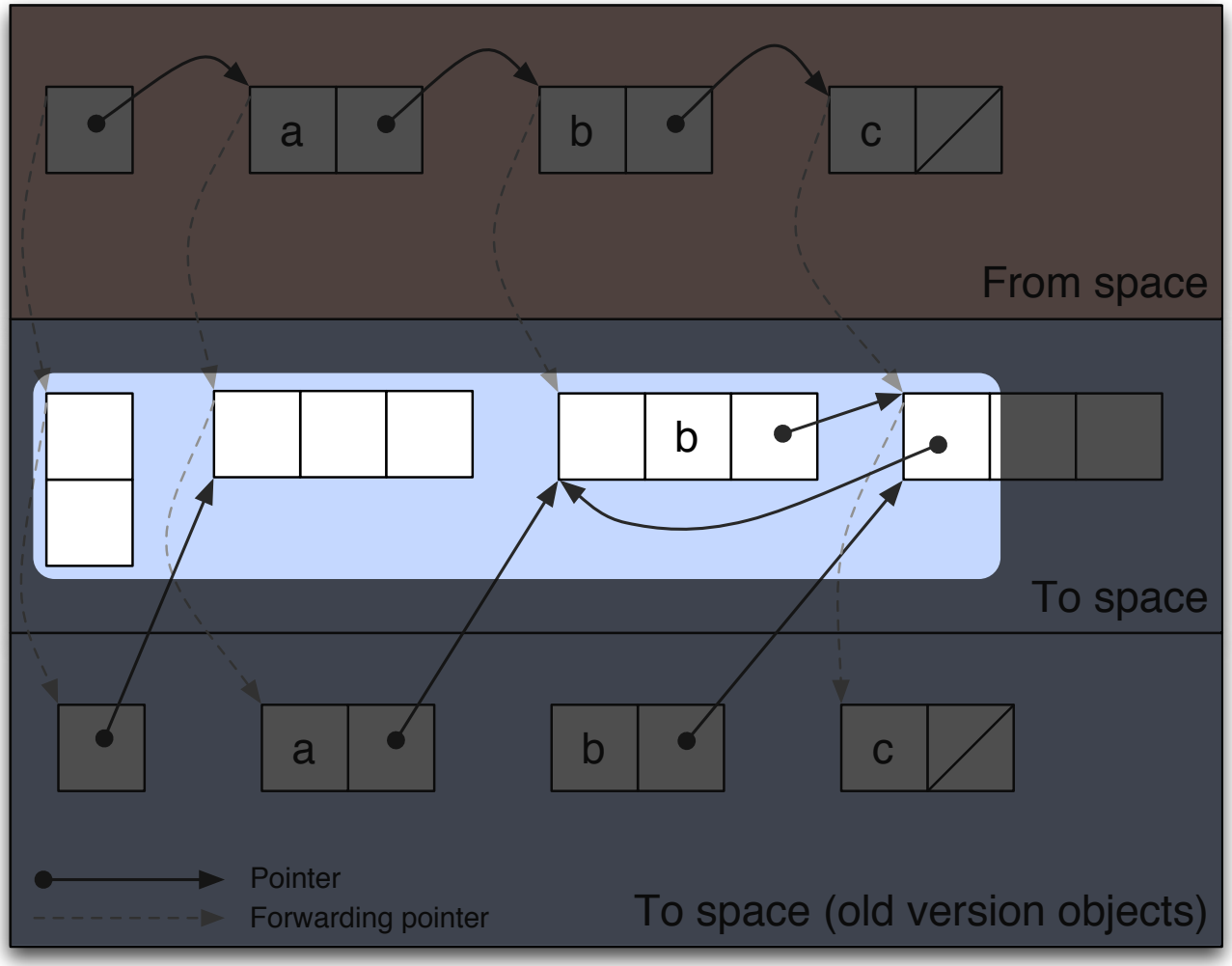
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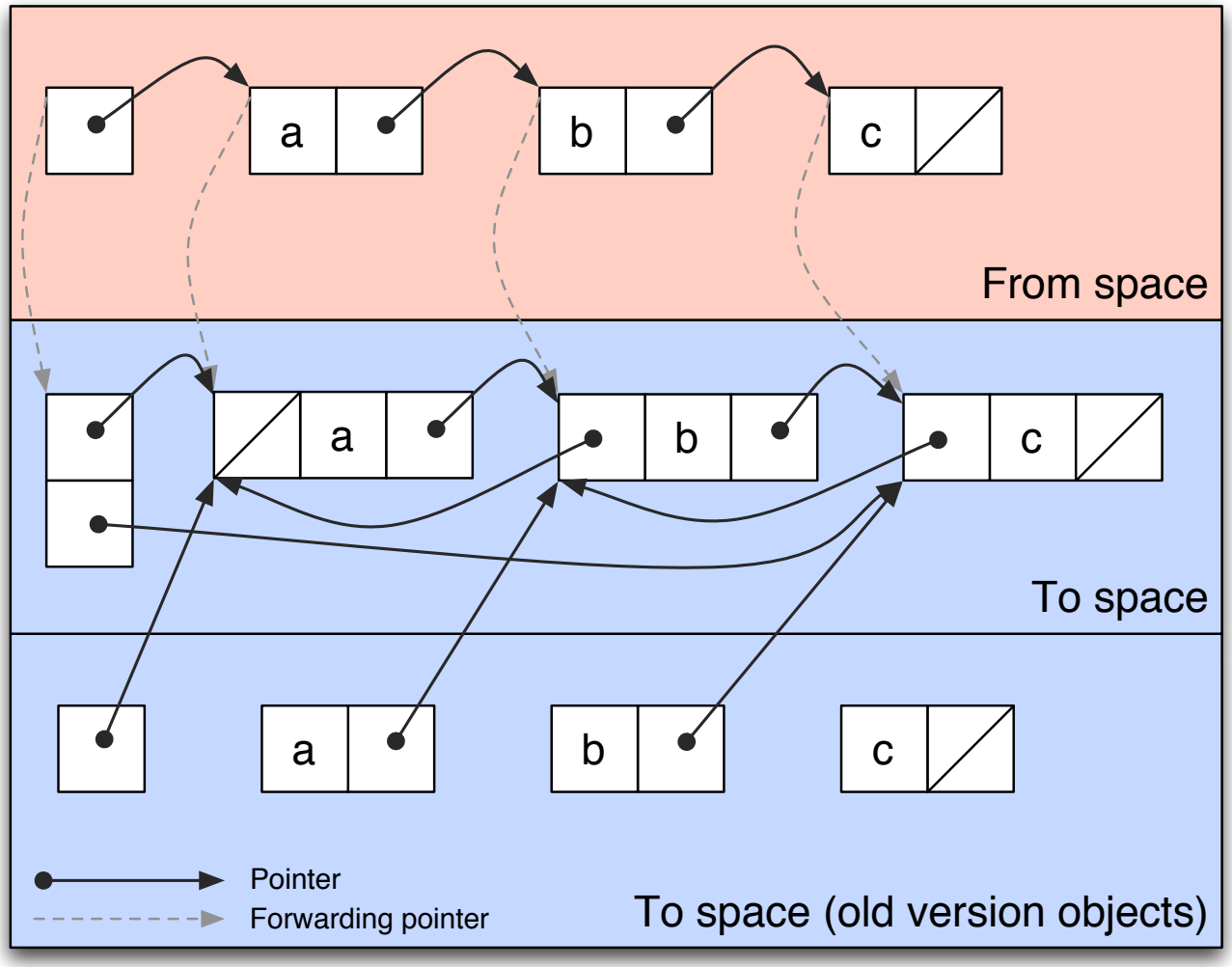
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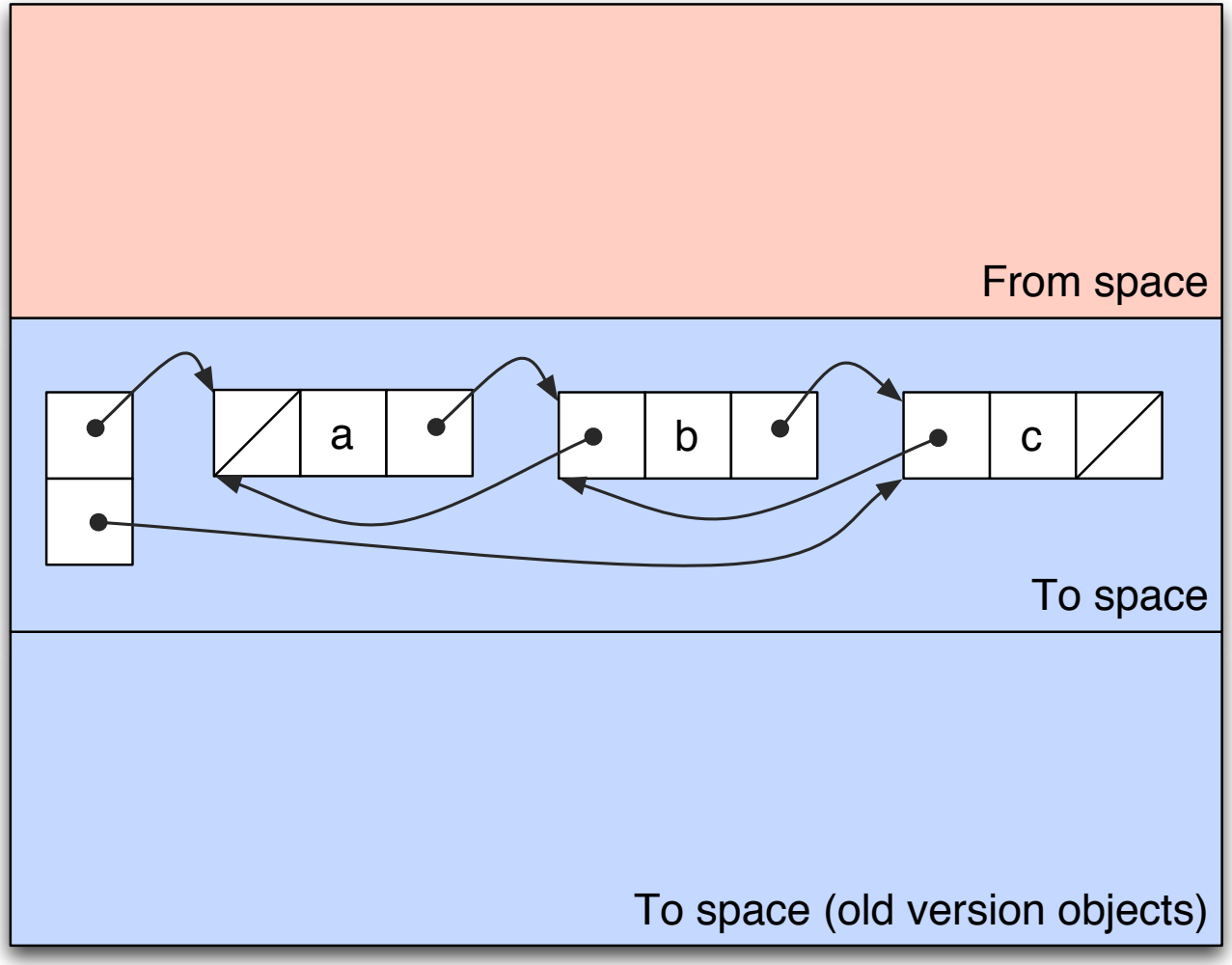


Application Experience

- 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

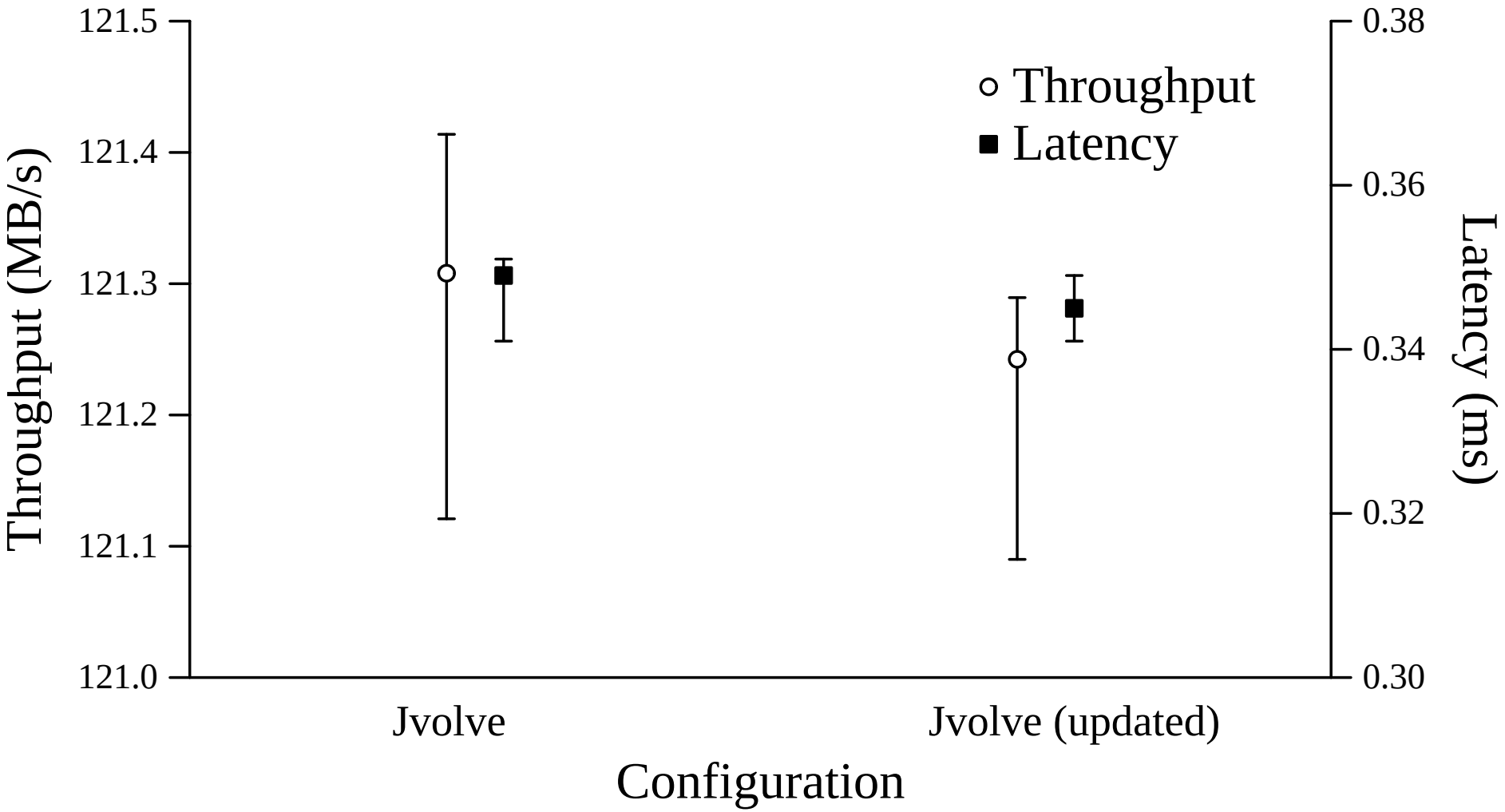
What works

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

JVOLVE performance

No overhead during steady-state execution



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.

Source code and other information:
`http://www.cs.utexas.edu/~suriya/jvolve`