Live Update: The Making of

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If We Functioned Like Computers. . .

Solutions

"If you think database patching is onerous,
then try patching a SCADA system
that's running a power plant."

Kelly Jackson Higgins on the SCADA patch problem, 2013

Solution 1: "Spare time for downtime"

Solutions

"In one of the biggest computer errors in banking history, Chemical Bank mistakenly deducted about $15 million from more than 100,000 customers' accounts."

Saul Hansell, New York Times, 1994

Solution 2: "Roll your upgrades"

Solutions

"Our research shows that 75% of successful attacks occur against previously known vulnerabilities for which a remediation was already available."

Neil MacDonald, Gartner Research, 2012

Solution 3: "Don't patch, don't tell"

Solutions

"All problems in computer science can be solved by another level of indirection—but that will usually create another problem."

Butler Lampson, quoting David Wheeler

Our solution: "Live update"

Live Update in the Real World

ORACLE | Ksplice

Servers protected with Ksplice Uptrack:
100,000+ at more than **700 companies**

Updates applied on production systems:
More than **2 million** and counting

How it works

Your Linux vendor releases an update.

Ksplice converts the upate into a rebootless update.

You install the update seamlessly, without rebooting.

Source: `http://www.ksplice.com`

Are We There Yet?

```
--- a/drivers/md/dm-crypt.c
+++ b/drivers/md/dm-crypt.c
@@ -690,6 +690,8 @@ bad3:
 bad2:
     crypto_free_tfm(tfm);
 bad1:
+    /* Must zero key material before freeing */
+    memset(cc, 0, sizeof(*cc) + cc->key_size * sizeof(u8));
     kfree(cc);
     return -EINVAL;
 }
@@ -706,6 +708,9 @@ static void crypt_dtr(...)
         cc->iv_gen_ops->dtr(cc);
     crypto_free_tfm(cc->tfm);
     dm_put_device(ti, cc->dev);
+
+    /* Must zero key material before freeing */
+    memset(cc, 0, sizeof(*cc) + cc->key_size * sizeof(u8));
     kfree(cc);
 }
```

Linux kernel security patch for CVE-2006-0095

Existing Live Update Solutions for C

Safe update state

- Update-agnostic characterization, e.g., no updates to active code.
- Problem: extensive patch inspection required for update safety.

State transfer

- Automatic generation of basic type transformers.
- Problem: significant programming effort for complex updates.

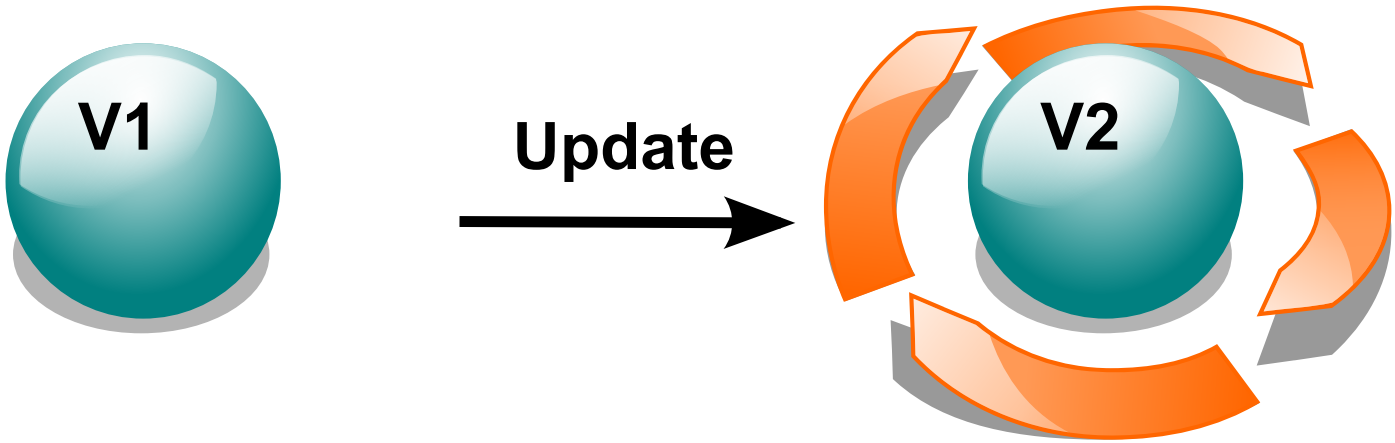
Live update mechanisms

- In-place "*hot patching*" update strategy.
- Problem: *unstable* live update process.

WWW: What We Want

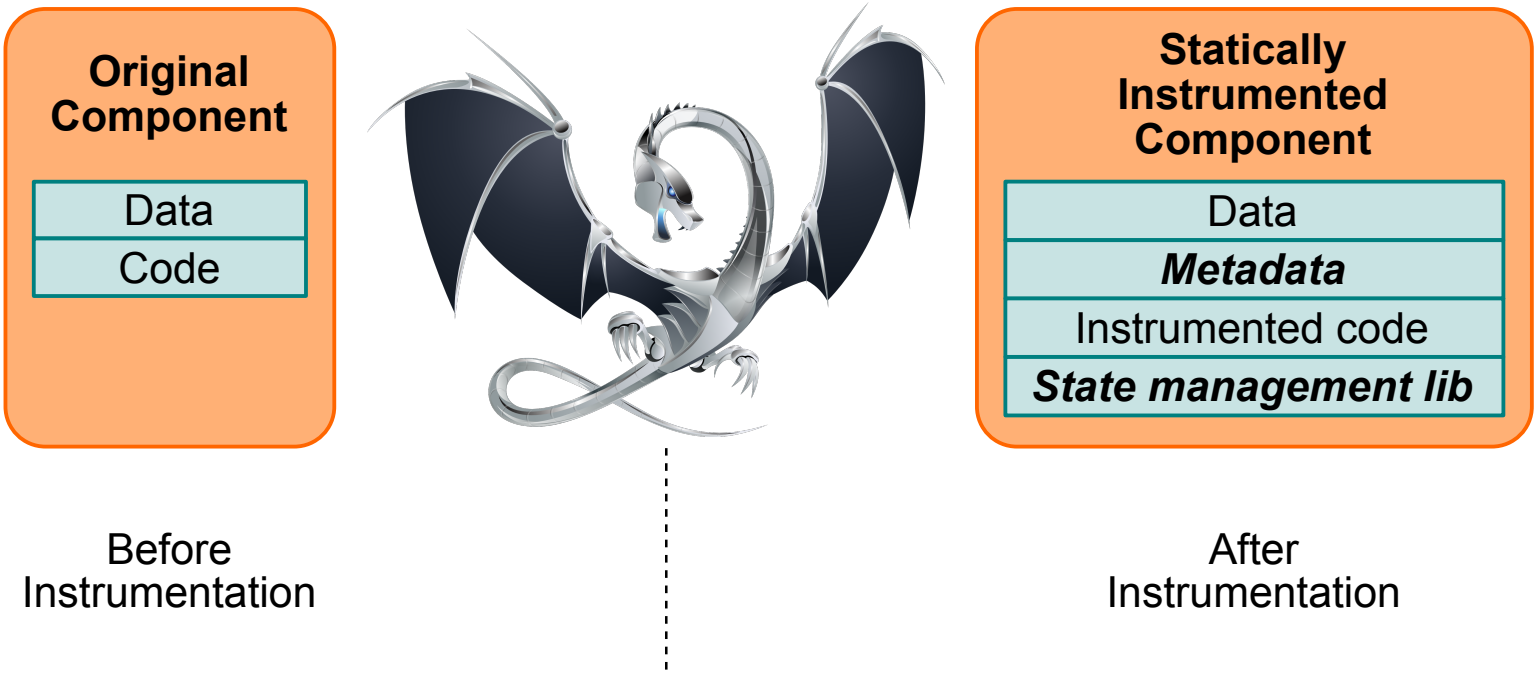
- Support for simple and complex updates of different natures.
- Safe and predictable live update process.
- Automated state transfer and state checking.
- Automatic error recovery (*hot rollback*).
- Stable live update process.

Our Live Update Design



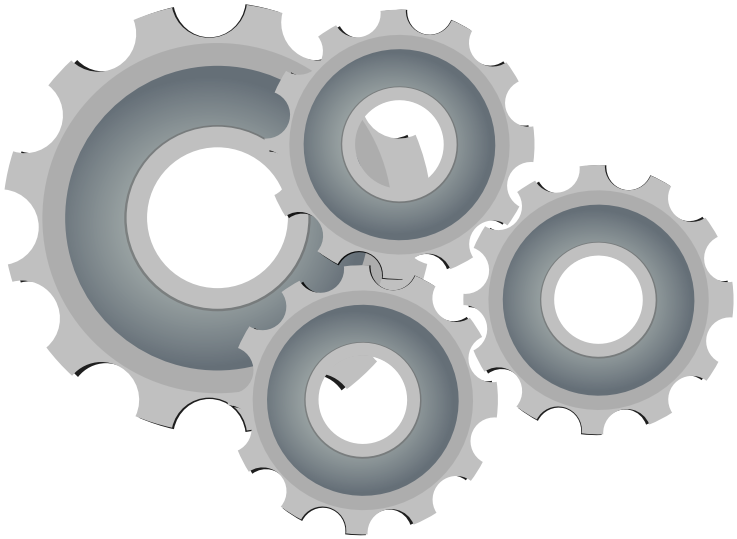
Process-level updates

Our Live Update Design



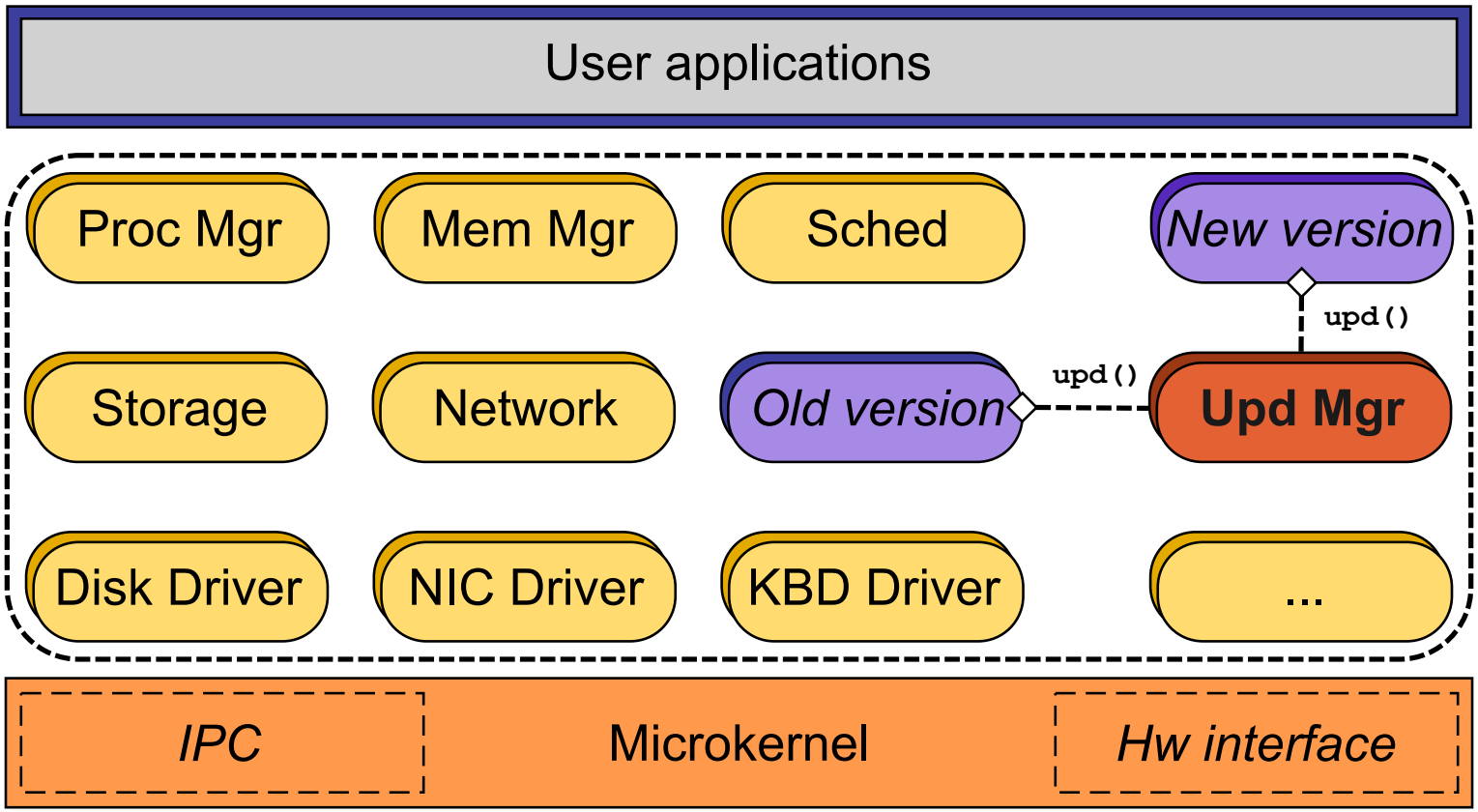
Compiler-based state instrumentation

Our Live Update Design



Controlled live update transaction

PROTEOS Architecture



PROTEOS Programming Model

```
static int my_init() {
  ... //initialization code
  return 0;
}
int main() {
  event_eh_t my_ehs = {init : my_init};
  sys_startup(&my_ehs);
  while(1) { // event loop
    msg_t m;
    sys_receive(&m);
    process_msg(&m);
  }
  return 0;
}
```

Event-driven model

PROTEOS Programming Model

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static int my_init() {
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Entry point

PROTEOS Programming Model

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  while(1) { // event loop
    msg_t m;
    sys_receive(&m);
    process_msg(&m);
  }
  return 0;
}
```

Update point

Live Update Example

```
% prctl mupdate net /bin/net.new \
      -state 'num_pending_writes == 0'

% prctl mupdate e1000 /bin/e1000.new

% prctl mupdate-start

UM: Live update requested for net, e1000.
UM: Loading /bin/net.new in memory...
UM: Loading /bin/e1000.new in memory...
UM: Applying changes...
UM: Cleaning up old version...
UM: Live update done.
```

Multi-component live update

Live Update Example

```
% prctl mupdate net /bin/net.new \
      -state 'num_pending_writes == 0'

% prctl mupdate e1000 /bin/e1000.new

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UM: Loading /bin/net.new in memory...
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```

State filter

Live Update Example

```
% prctl mupdate net /bin/net.new \
      -state 'num_pending_writes == 0'

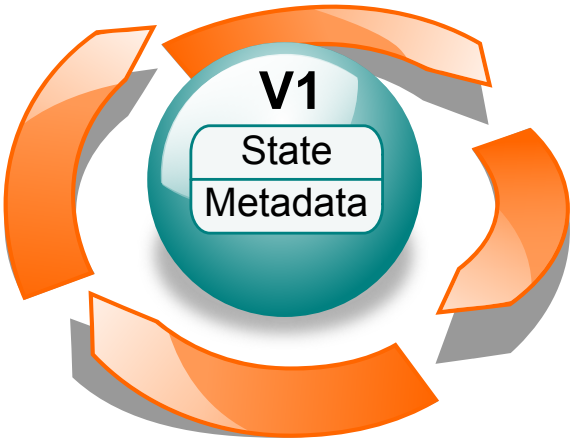
% prctl mupdate e1000 /bin/e1000.new

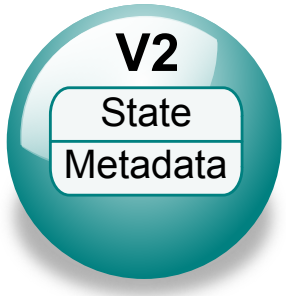
% prctl mupdate-start
```

```
UM: Live update requested for net, e1000.
UM: Loading /bin/net.new in memory...
UM: Loading /bin/e1000.new in memory...
UM: Applying changes...
UM: Cleaning up old version...
UM: Live update done.
```

Changes applied automatically

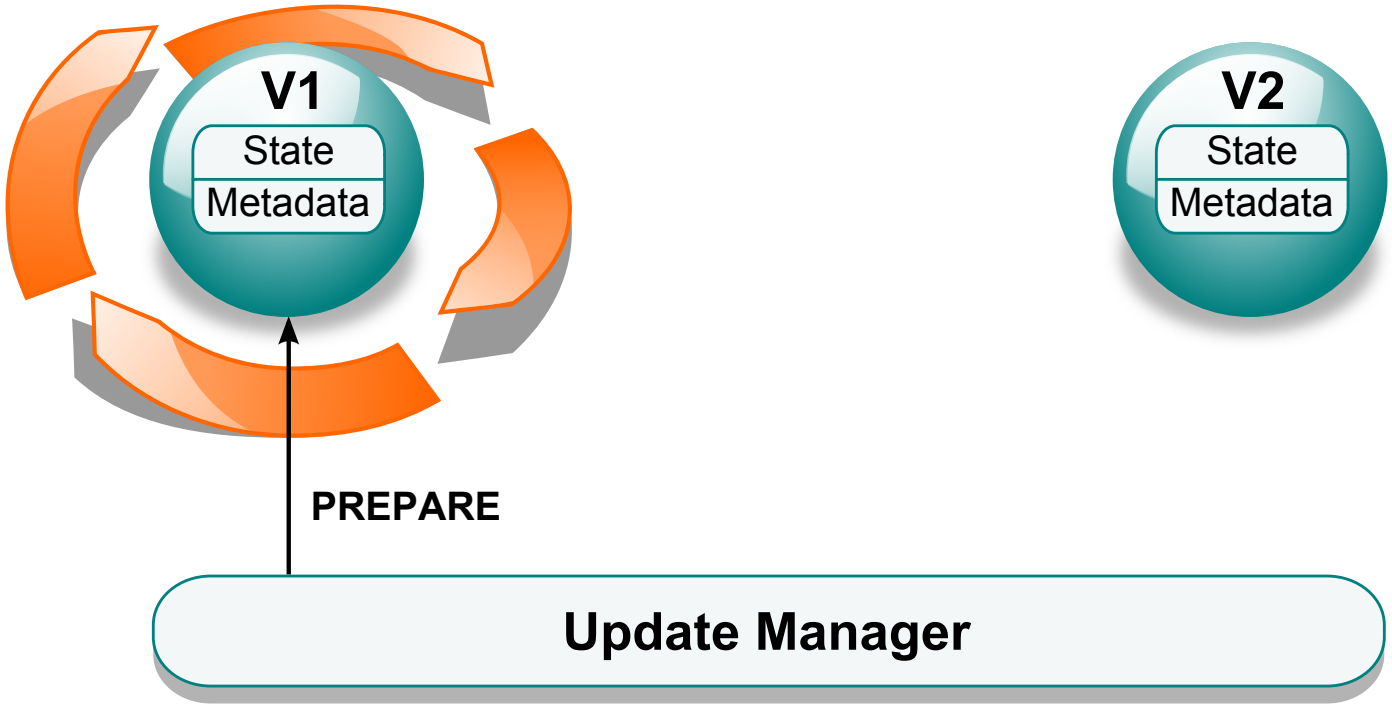
The Live Update Process



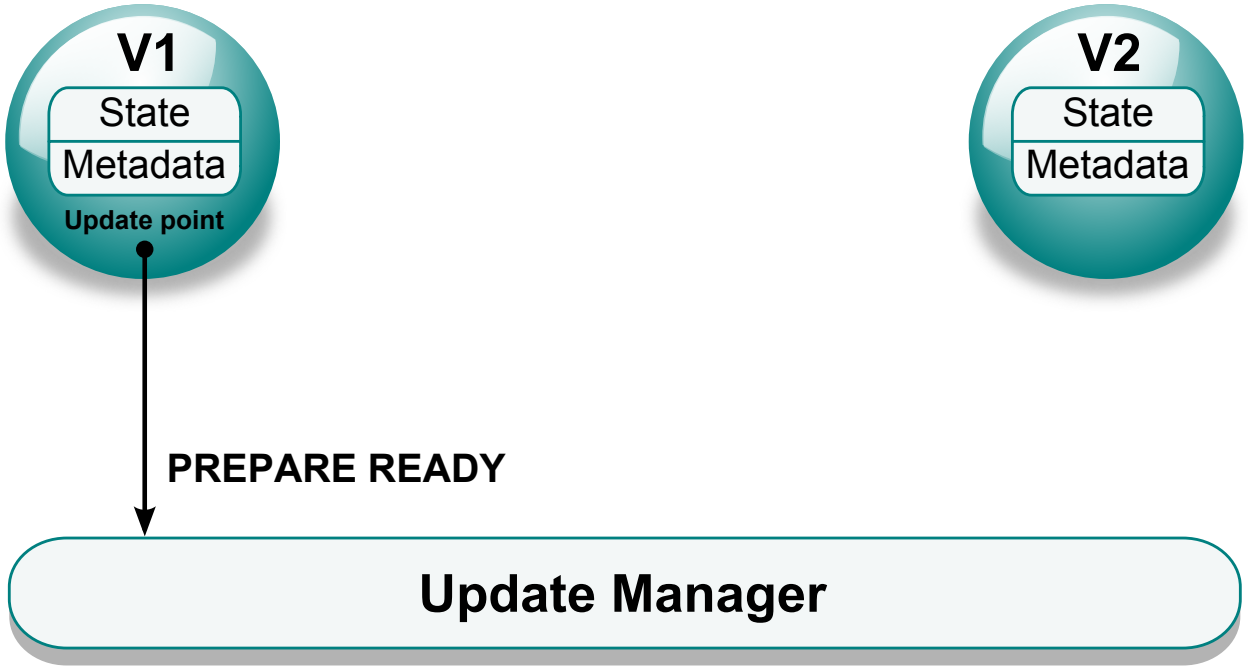


Update Manager

The Live Update Process



The Live Update Process



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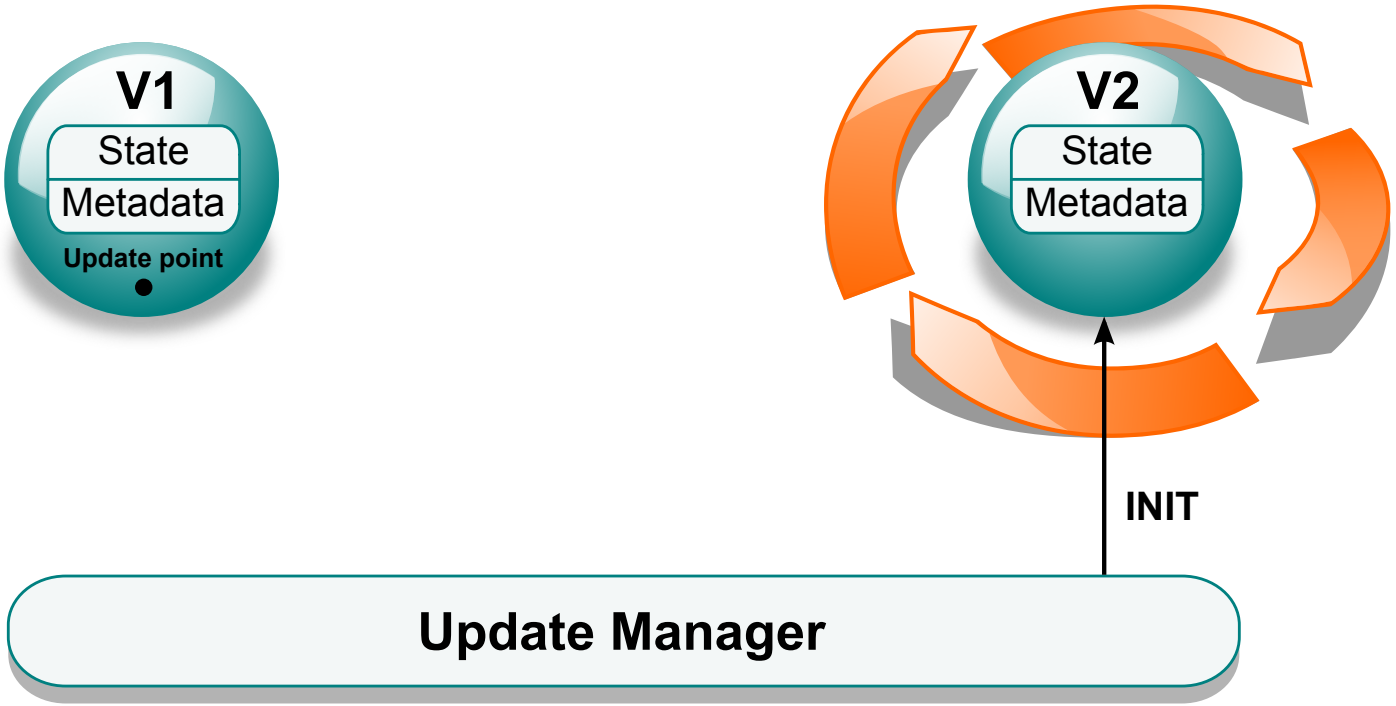

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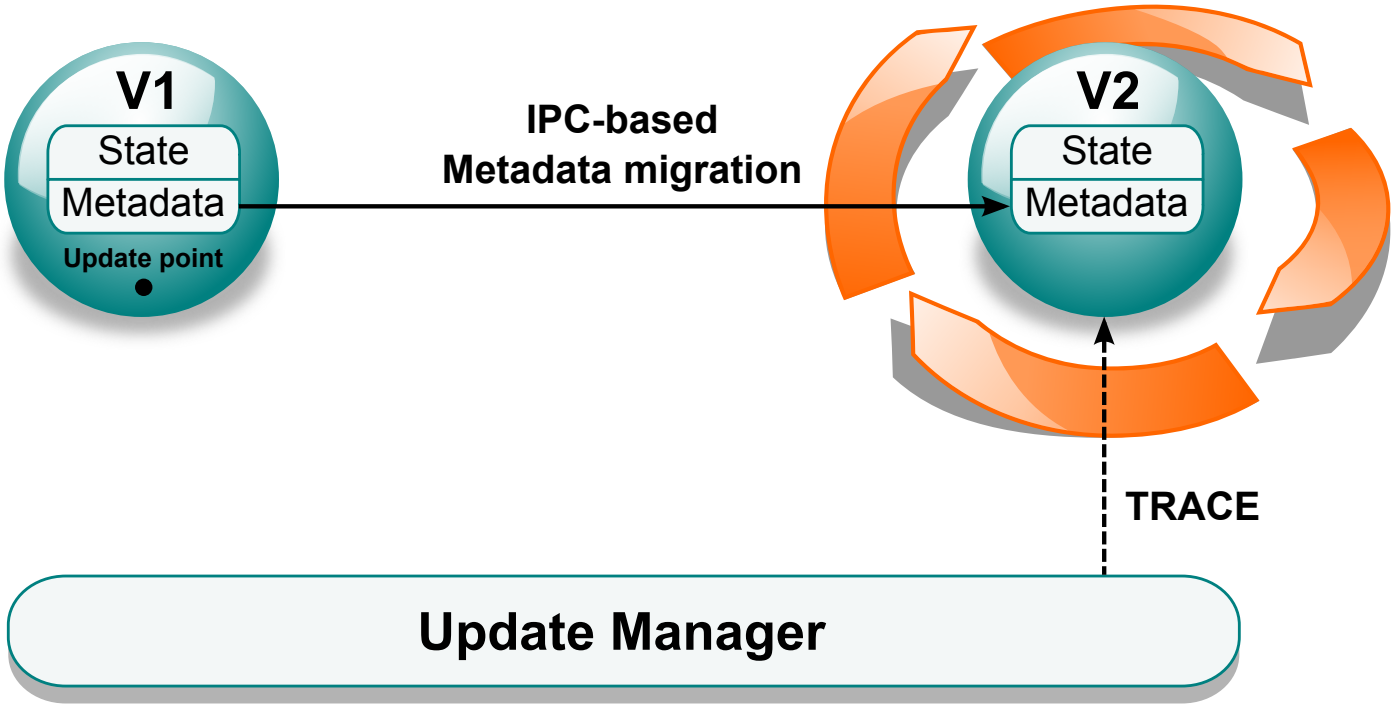

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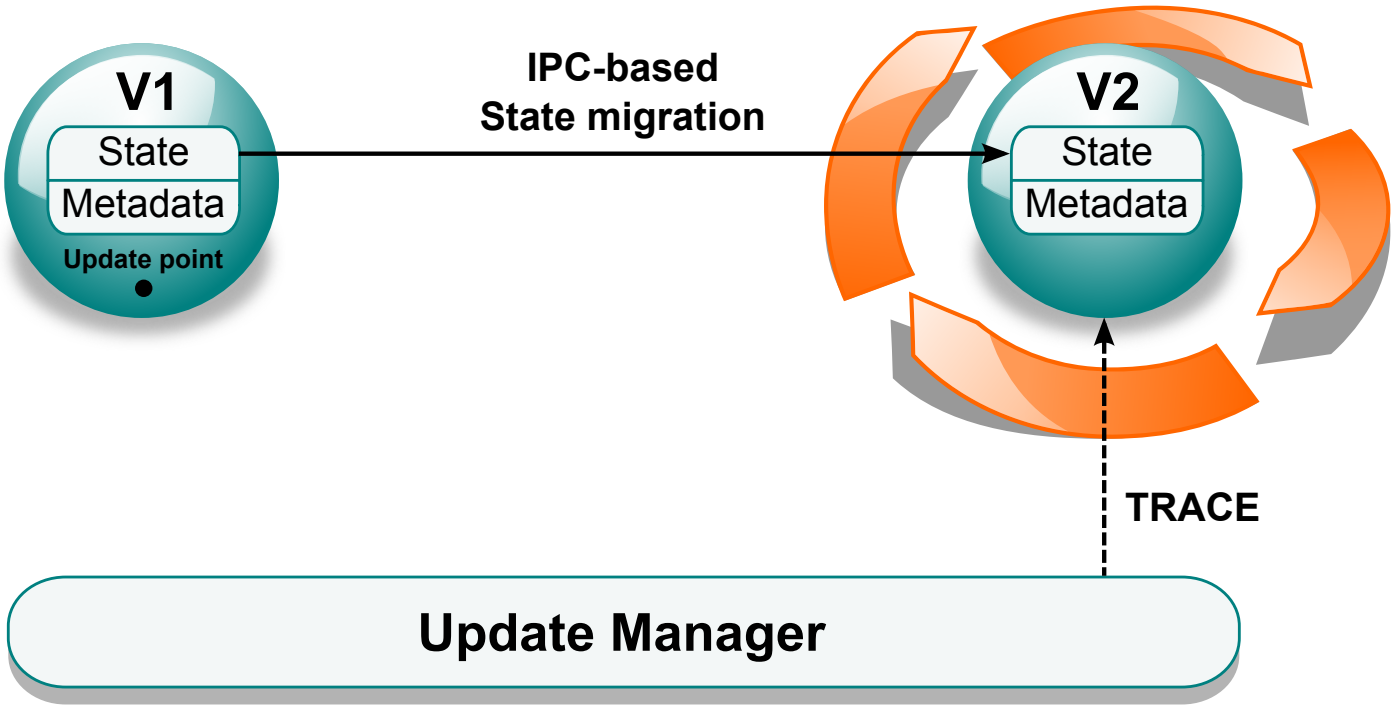
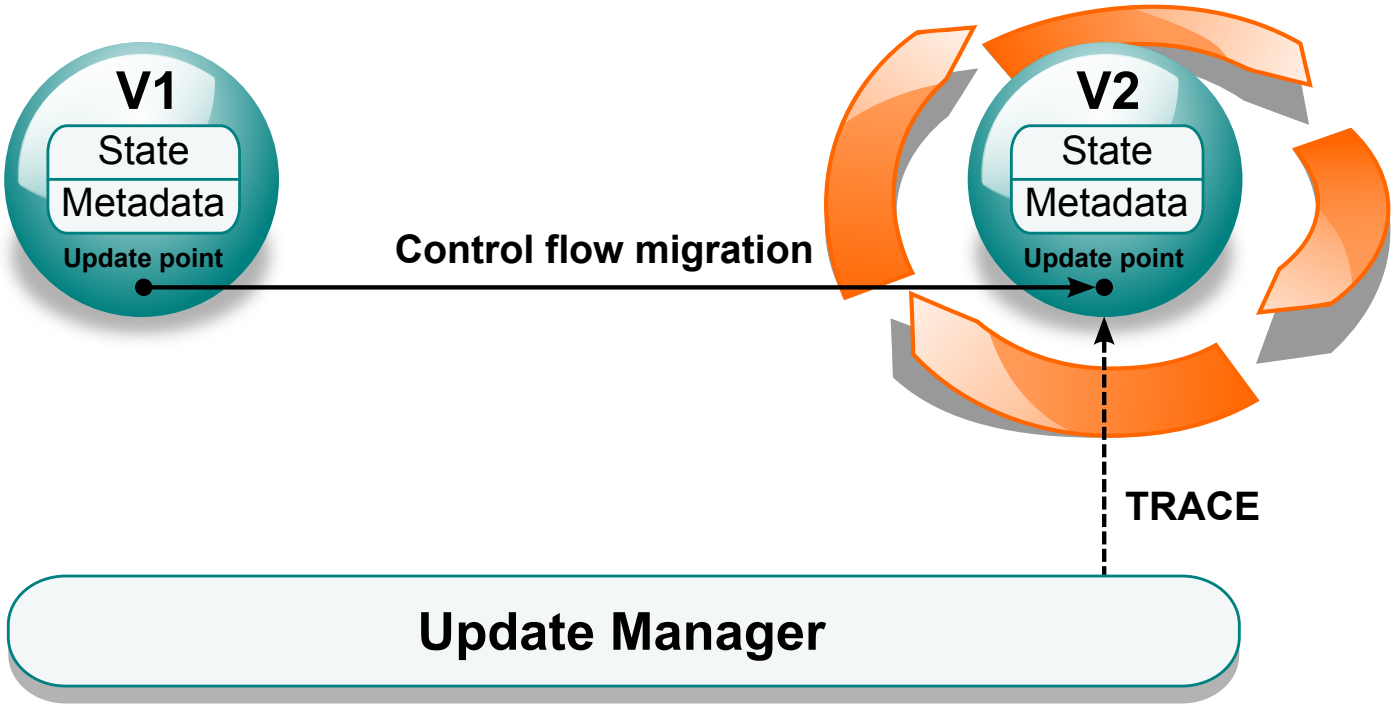


The Live Update Process



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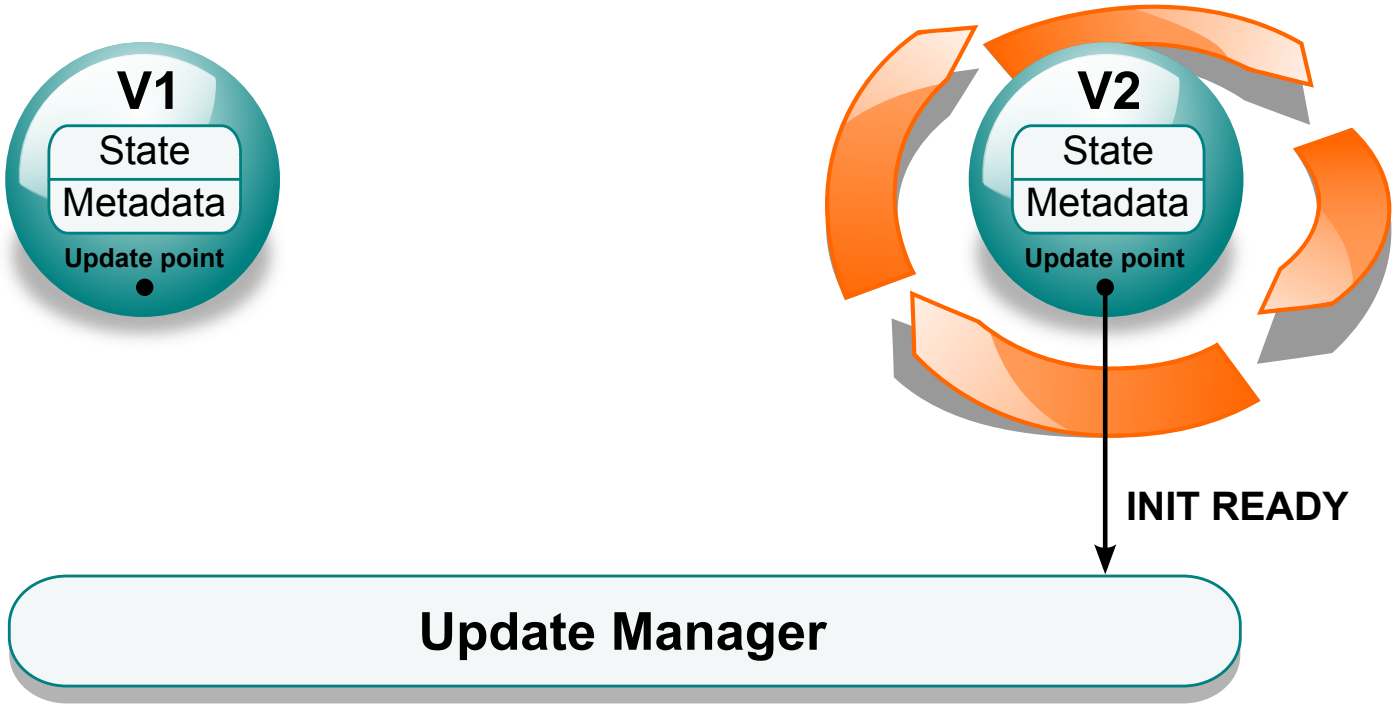

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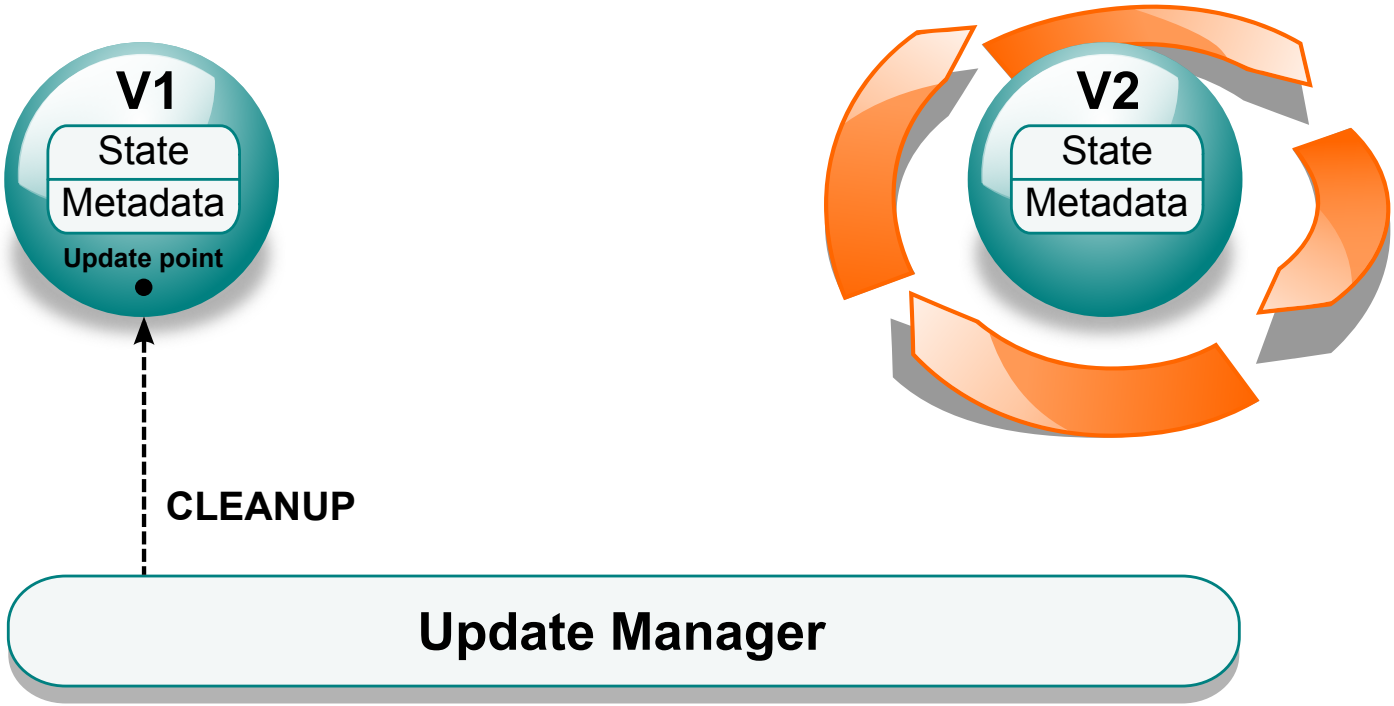

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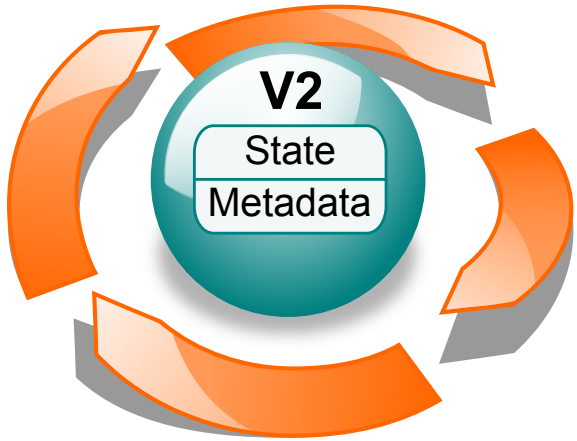
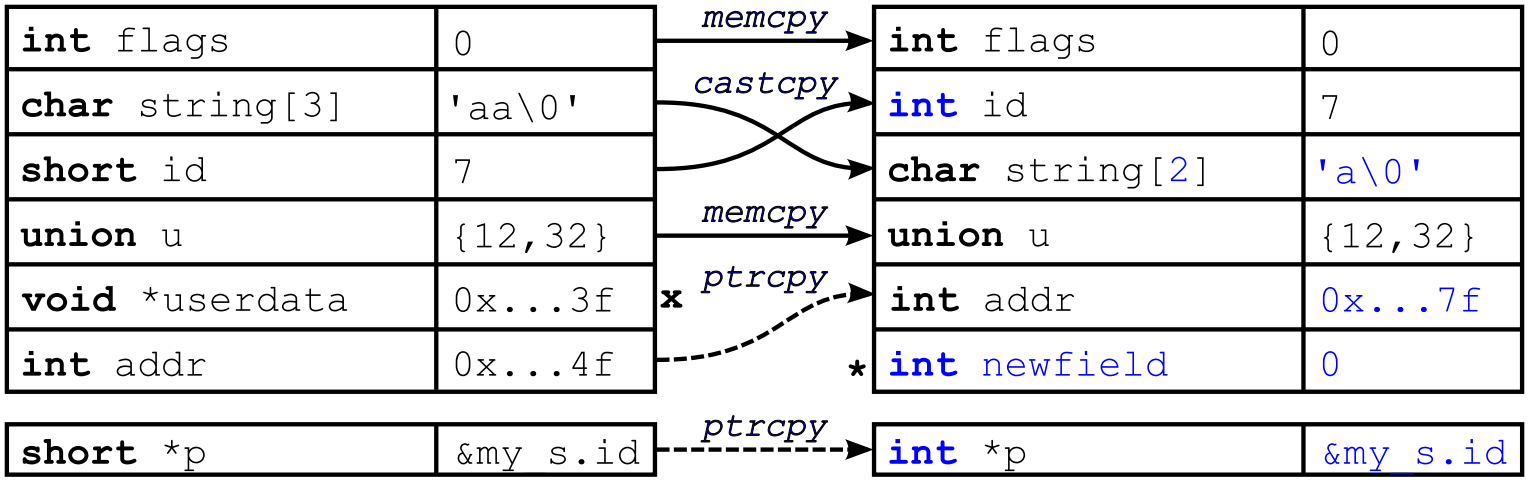


Update Manager

Transfer Strategy

```
struct s { //old version
    int flags;
    char string[3];
    short id;
    union IXFER(my_u) u;
    void *userdata;
    PXFER(int) addr;
} my_s;
short *p = &my_s.id;
```

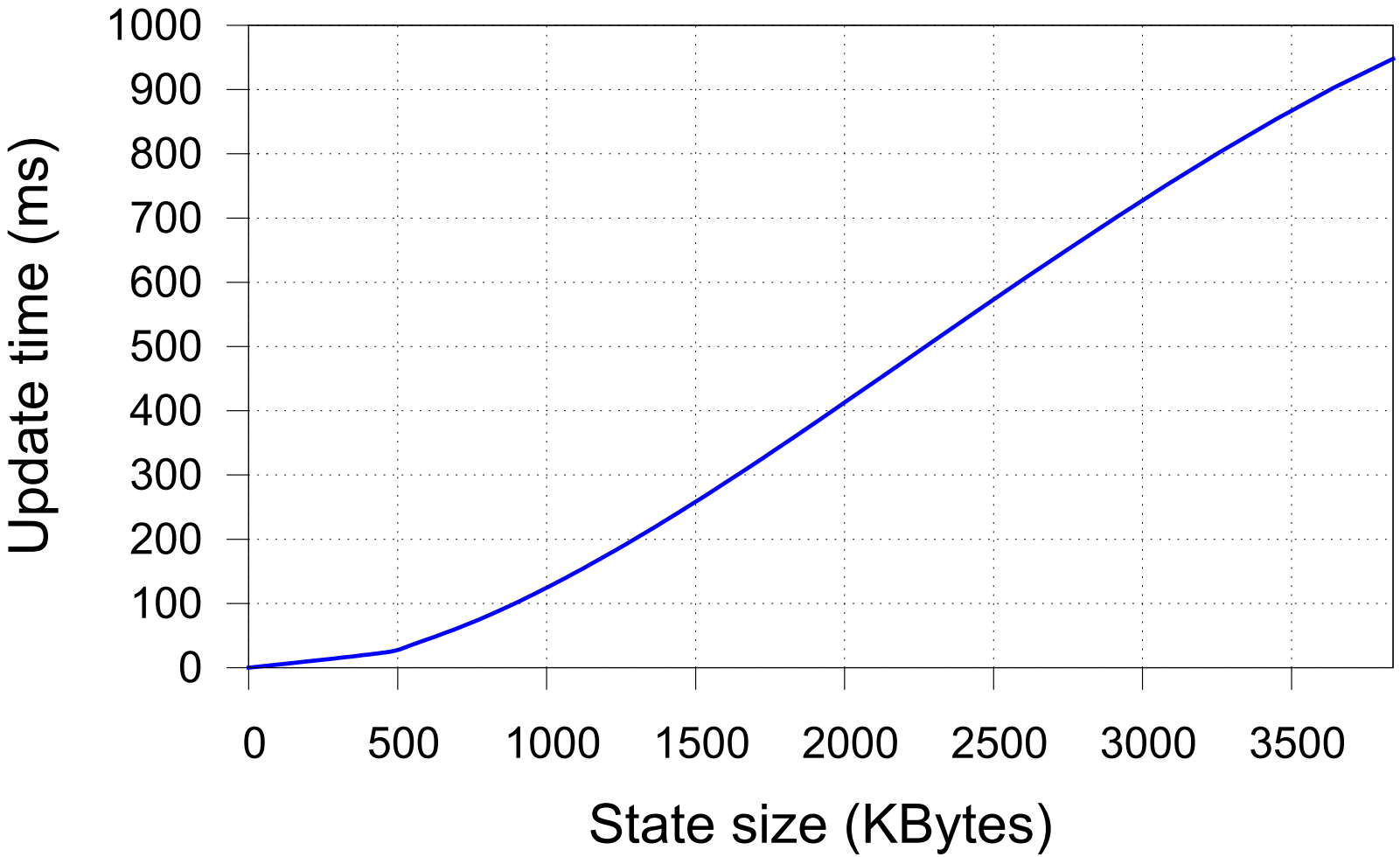
```
struct s { //new version
    int flags;
    int id;
    char string[2];
    union IXFER(my_u) u;
    PXFER(int) addr;
    int newfield;
} my_s;
int *p = &my_s.id;
```



Experience

- Applied 50 real updates (∼15000 LOC) with only 265 ST LOC.
- Written 14 state annotations and 4 state filters.
- Median patch size is more than 10x higher than Ksplice's.
- Instrumentation cost isolated in allocator operations (1.06-2.30x).
- Instrumentation yields a modest memory overhead (∼0.35x).

Update Time


Update time (ms)
1000
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
State size (KBytes)

Summary

- PROTEOS: a new research OS designed with live update in mind.
- Supports several classes of updates with minimal manual effort.
- Full control over the live update transaction.
- Simple and stable live update process.
- Automated and extensible state transfer and state checking.
- State transfer error detection and recovery using hot rollback.

Live Update: The Making of

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