Undo

—

Record, Replay, Rinse, & Repeat: Easily Rebuilding Programmatic State

Greg Law, co-founder & CTO

tl;dr

- Debugging dominates software development
  - Which means answering the question “what happened?”
- Record & replay is a new approach where the computer can just tell you
- Bugs can be fixed orders of magnitude more quickly

- Most software is not truly understood by anyone

In the beginning

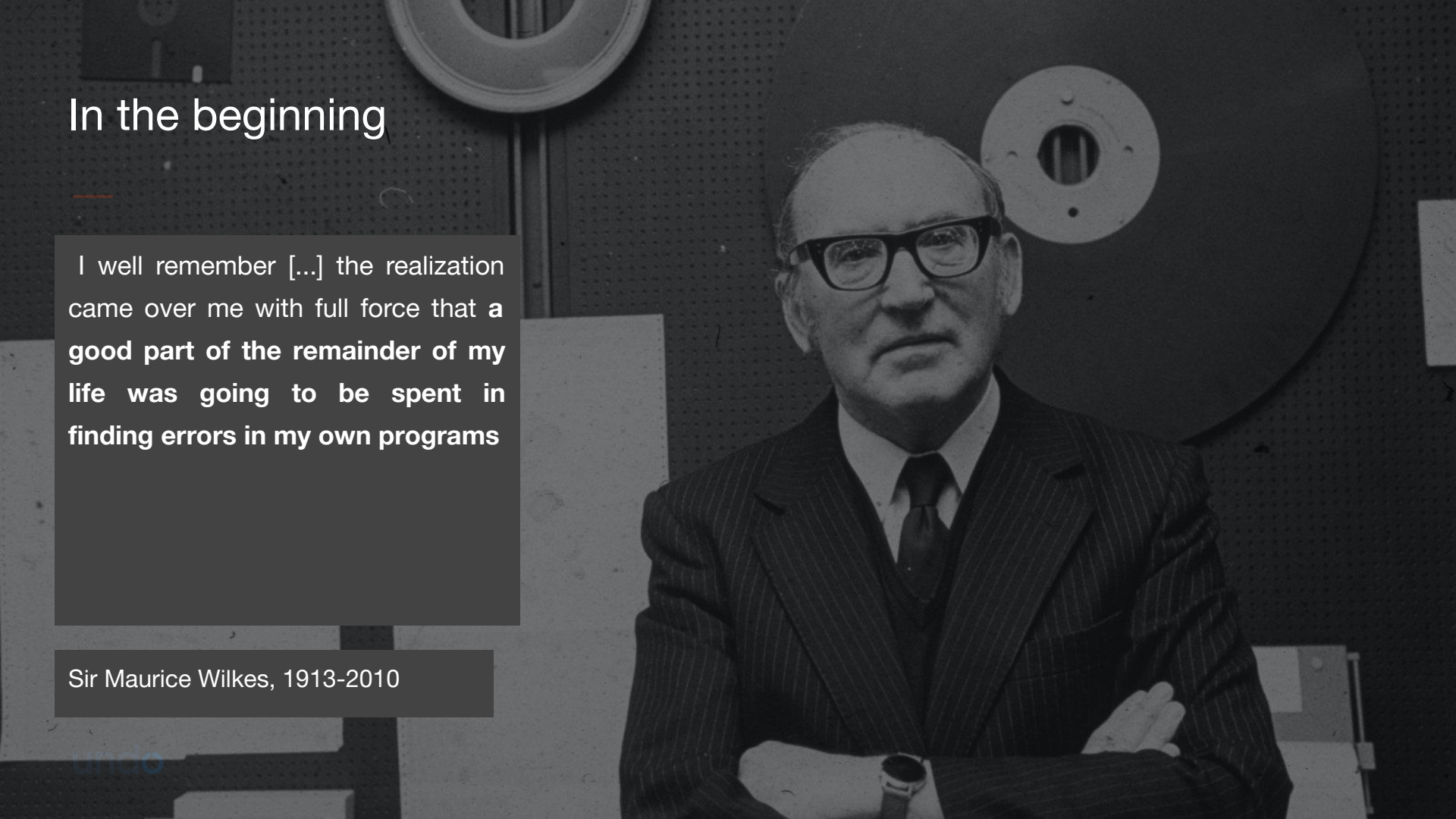
Sir Maurice Wilkes, 1913-2010

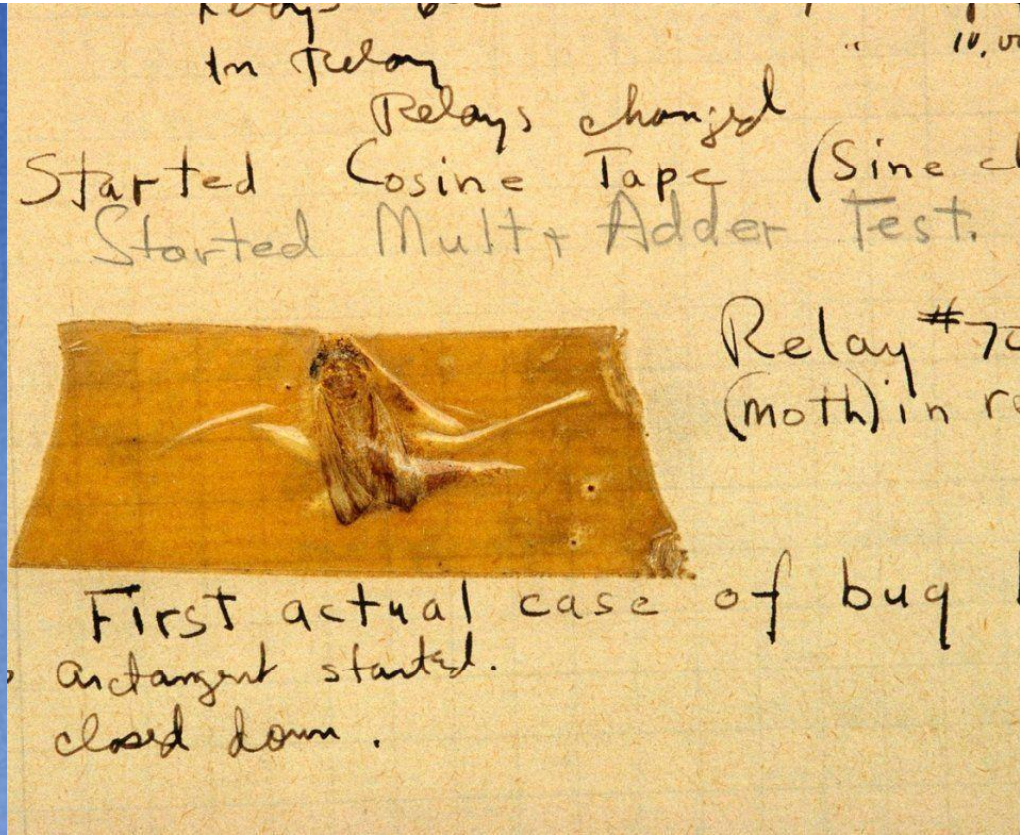

FRIDEN

In the beginning

I well remember [...] the realization came over me with full force that **a good part of the remainder of my life was going to be spent in finding errors in my own programs**

Sir Maurice Wilkes, 1913-2010




Relays changed
Started Cosine Tape
Started Mult + Adder Test.
Relay #
(moth) in
First actual case of bug
closed down.

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Computers are hard


cadence

Everyone knows that debugging is twice as hard as writing a program in the first place. So if you're as clever as you can be when you write it, how will you ever debug it?

Brian Kernighan

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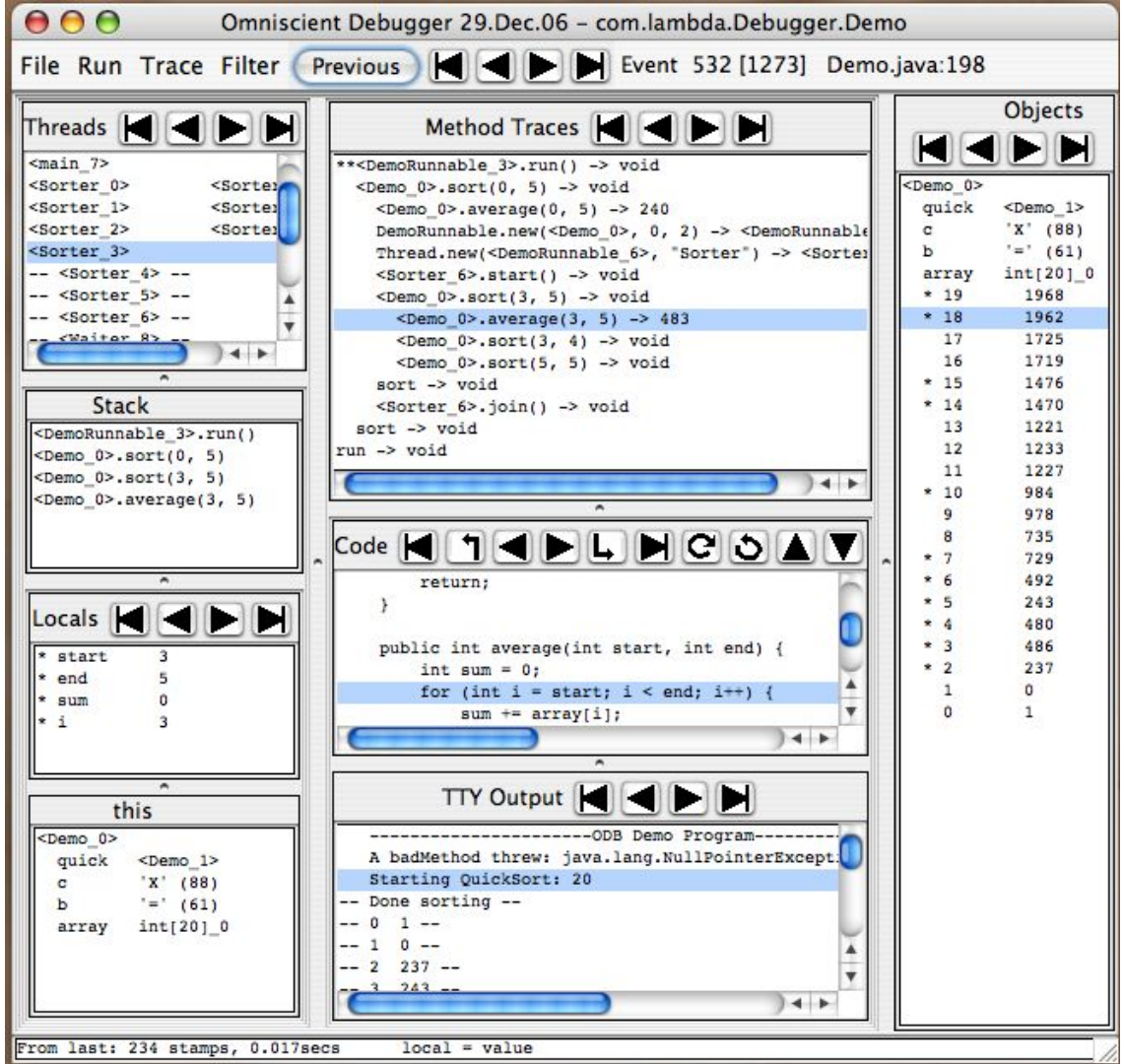
What happened?

What makes bugs really hard?


Omniscient Debugger 29.Dec.06 – com.lambda.Debugger.Demo
File Run Trace Filter Previous Event 532 [1273] Demo.java:198
Threads
<main_7>
<Sorter_0>
<Sorter_1>
<Sorter_2>
<Sorter_3>
-- <Sorter_4> --
-- <Sorter_5> --
-- <Sorter_6> --
Stack
<DemoRunnable_3>.run()
<Demo_0>.sort(0, 5)
<Demo_0>.sort(3, 5)
<Demo_0>.average(3, 5)
Locals
* start 3
* end 5
* sum 0
* i 3
this
<Demo_0>
quick <Demo_1>
c 'X' (88)
b '=' (61)
array int[20]_0
Method Traces
**<DemoRunnable_3>.run() -> void
<Demo_0>.sort(0, 5) -> void
<Demo_0>.average(0, 5) -> 240
DemoRunnable.new(<Demo_0>, 0, 2) -> <DemoRunnable
Thread.new(<DemoRunnable_6>, "Sorter") -> <Sorter
<Sorter_6>.start() -> void
<Demo_0>.sort(3, 5) -> void
<Demo_0>.average(3, 5) -> 483
<Demo_0>.sort(3, 4) -> void
<Demo_0>.sort(5, 5) -> void
sort -> void
<Sorter_6>.join() -> void
sort -> void
run -> void
Code
return;
}
public int average(int start, int end) {
int sum = 0;
for (int i = start; i < end; i++) {
sum += array[i];
TTY Output
----------ODB Demo Program----------
A badMethod threw: java.lang.NullPointerExcept
Starting QuickSort: 20
-- Done sorting --
-- 0 1 --
-- 1 0 --
-- 2 237 --
Objects
<Demo_0>
quick <Demo_1>
c 'X' (88)
b '=' (61)
array int[20]_0
* 19 1968
* 18 1962
17 1725
16 1719
* 15 1476
* 14 1470
13 1221
12 1233
11 1227
* 10 984
9 978
8 735
* 7 729
* 6 492
* 5 243
* 4 480
* 3 486
* 2 237
1 0
0 1
From last: 234 stamps, 0.017secs local = value

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What was the previous state?

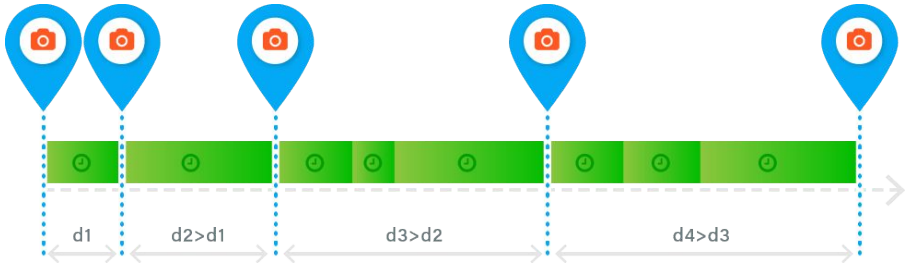
Two options:

1. Save it.
2. Recompute it.

$a = a + 1$ ✓

$a = b$ ✗

Snapshots



Maintain snapshots through history

Resume from these - run forward as needed

Copy-on-Write for memory efficiency

Adjust spacing to anticipate user's needs

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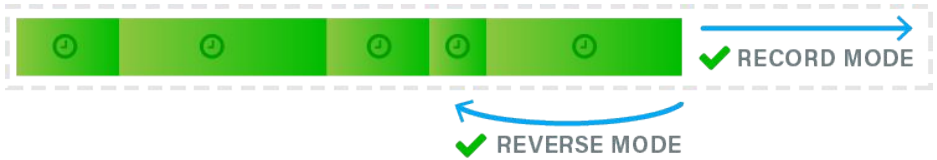
Event log



Event Log captures non-deterministic state

Stored in memory

Efficient, diff-based representation

Recorded during debug (or Live Recording)

Replayed to reconstruct any point in history

Saved to create a recording file for later use

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Instrumentation

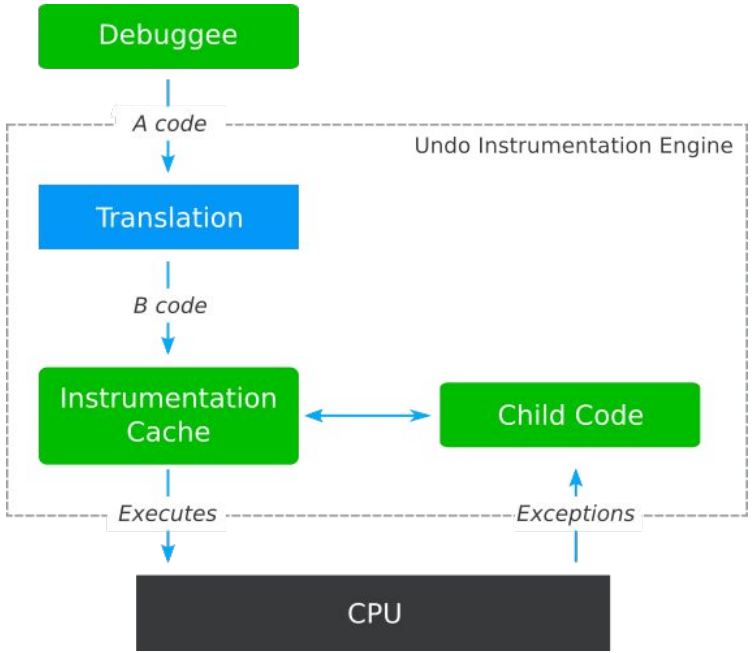
Undo Engine captures *all* non-determinism

Some machine instructions are non-deterministic

`rdtsc`, `cpuid`, `syscall`, etc

Needs to capture all this and provide precise control over execution in general

Solution: Runtime instrumentation



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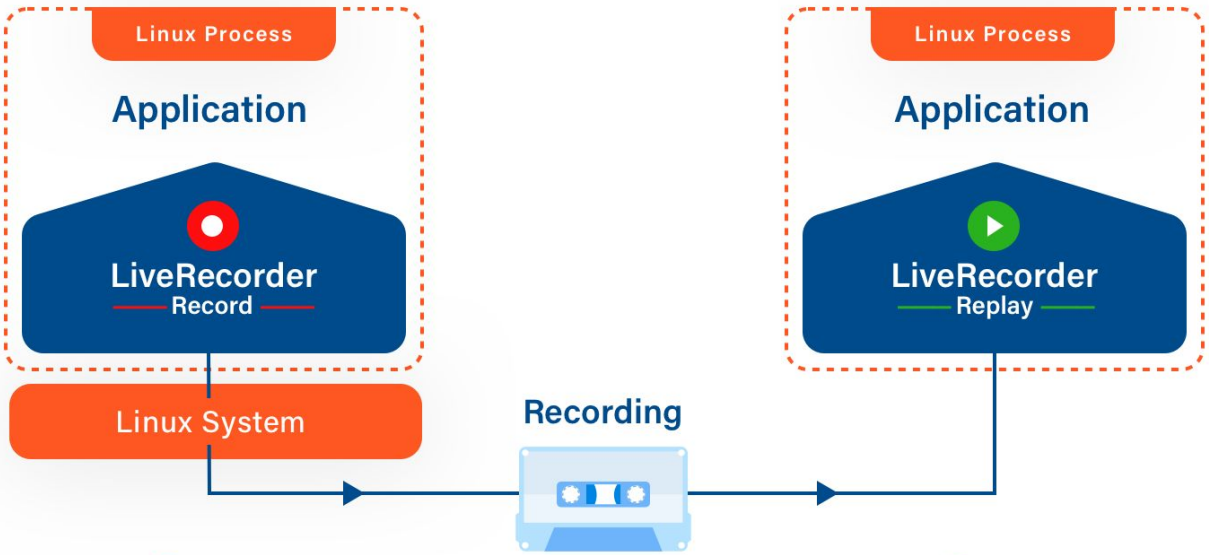
In-process Virtualization



Record

- Captures all state changes in a running process
- 100% reproduction of execution history

Replay

- Replay & analyze the recording
- Detect root cause of bug
- Reverse debug and resolve

Multiple implementations

For Linux:

- Undo LiveRecorder (C++, Go, Java)
- rr (C++, Go)
- gdb process record

For Windows:

- Microsoft's Time-Travel Debugger (C++, C#, Chakracore JS)
- RevDebug (C#, Java)

Works well in conjunction with live logging & tracing

Logging & tracing give a high-level ‘story’ of a program’s execution

Use it to know where to go in a recording

Apply logging to a recording

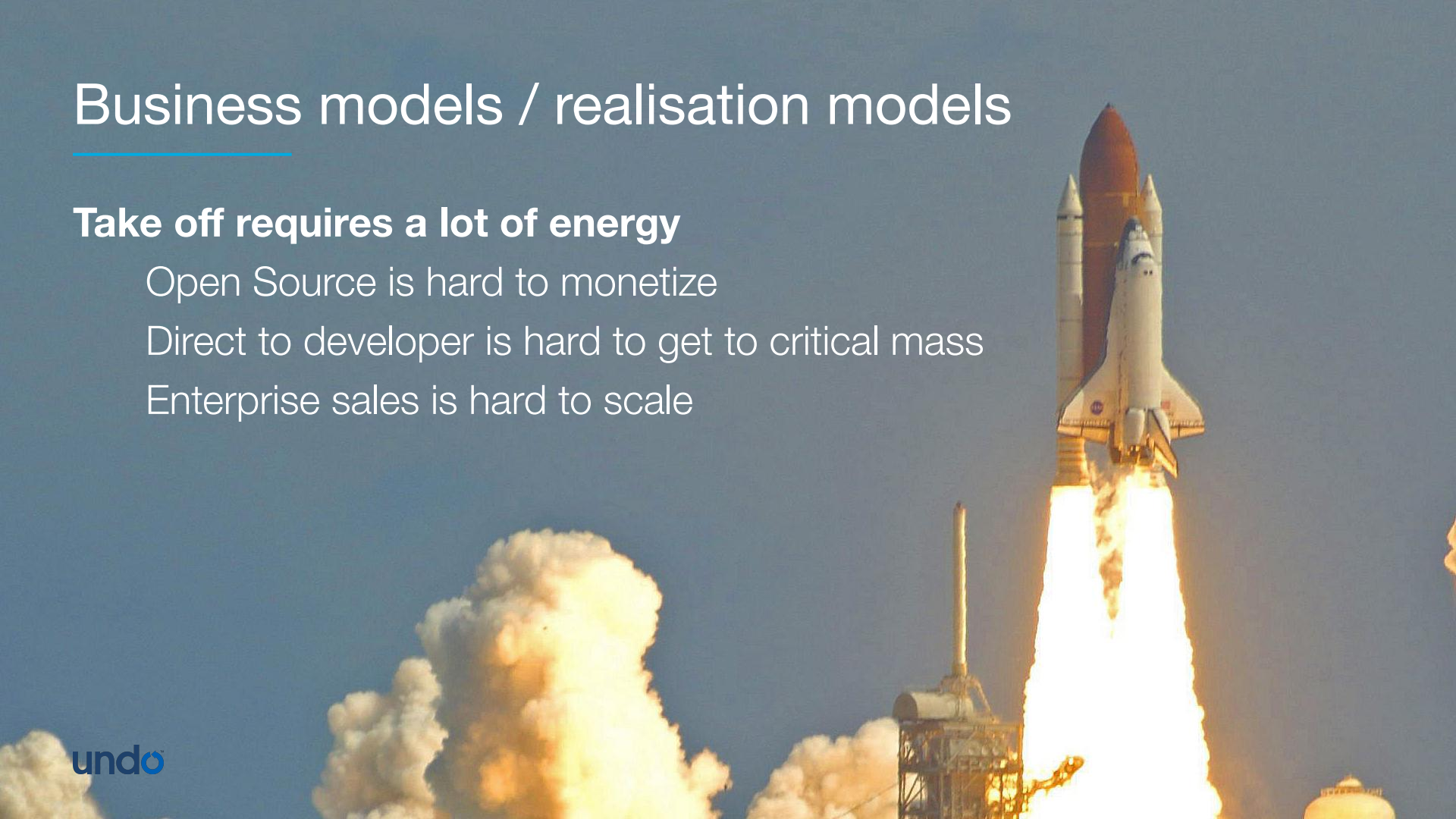
80/20 Rule

~~80/20 Rule~~

Business models / realisation models

Take off requires a lot of energy

- Open Source is hard to monetize
- Direct to developer is hard to get to critical mass
- Enterprise sales is hard to scale



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1. Computers are hard & debugging is under-served
2. Record/replay is awesome
3. 80/20 rule does not always apply