How Failures Come to be

Andreas Zeller

An F-16

(northern hemisphere)

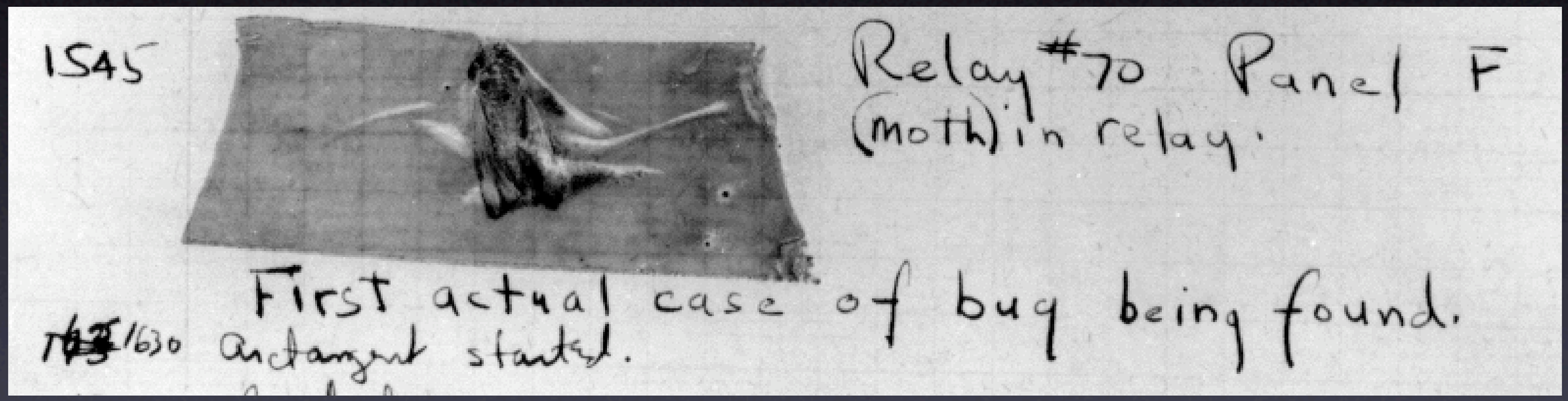
An F-16

(southern hemisphere)

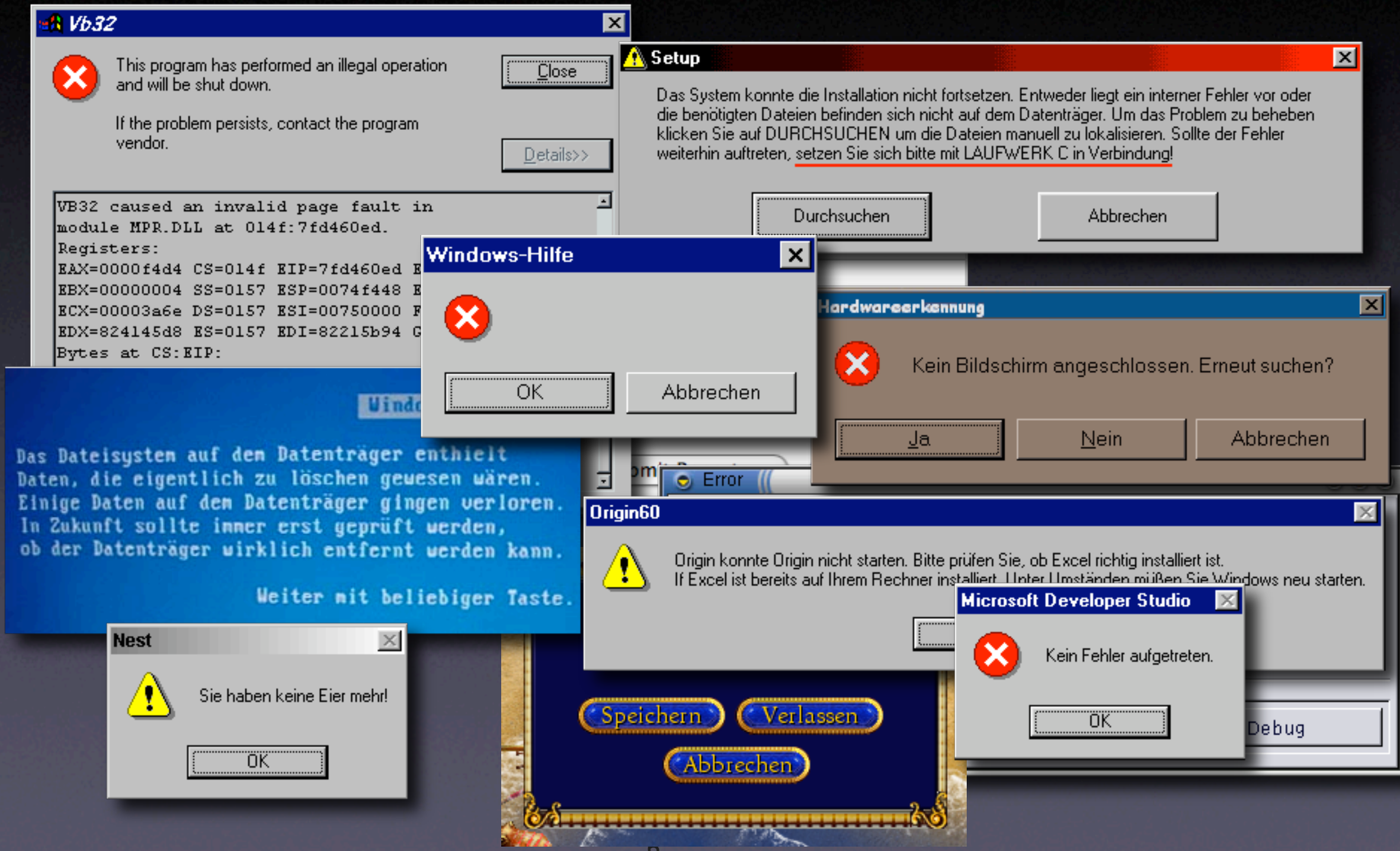
F-16 Landing Gear

The First Bug

September 9, 1947



More Bugs


Vb32
This program has performed an illegal operation and will be shut down.
If the problem persists, contact the program vendor.
Close
Details>>
VB32 caused an invalid page fault in
module MPR.DLL at 014f:7fd460ed.
Registers:
EAX=0000f4d4 CS=014f EIP=7fd460ed E
EBX=00000004 SS=0157 ESP=0074f448 E
ECX=00003a6e DS=0157 ESI=00750000 F
EDX=824145d8 ES=0157 EDI=82215b94 G
Bytes at CS:EIP:
Setup
Das System konnte die Installation nicht fortsetzen. Entweder liegt ein interner Fehler vor oder die benötigten Dateien befinden sich nicht auf dem Datenträger. Um das Problem zu beheben klicken Sie auf DURCHSUCHEN um die Dateien manuell zu lokalisieren. Sollte der Fehler weiterhin auftreten, setzen Sie sich bitte mit LAUFWERK C in Verbindung!
Durchsuchen
Abbrechen
Windows-Hilfe
OK
Abbrechen
Hardwareerkennung
Kein Bildschirm angeschlossen. Erneut suchen?
Ja
Nein
Abbrechen
Das Dateisysten auf den Datenträger enthielt
Daten, die eigentlich zu löschen gewesen wären.
Einige Daten auf dem Datenträger gingen verloren.
In Zukunft sollte immer erst geprüft werden,
ob der Datenträger wirklich entfernt werden kann.
Weiter mit beliebiger Taste.
Error
Origin60
Origin konnte Origin nicht starten. Bitte prüfen Sie, ob Excel richtig installiert ist.
If Excel ist bereits auf Ihrem Rechner installiert. Unter Umständen müßen Sie Windows neu starten.
Microsoft Developer Studio
Kein Fehler aufgetreten.
OK
Nest
Sie haben keine Eier mehr!
OK
Speichern
Verlassen
Abbrechen
Debug

Facts on Debugging

- Software bugs are costing ~60 bln US$/yr
- Improvements could reduce cost by 30%
- Validation (including debugging) can easily take up to 50-75% of the development time
- When debugging, some people are three times as efficient than others

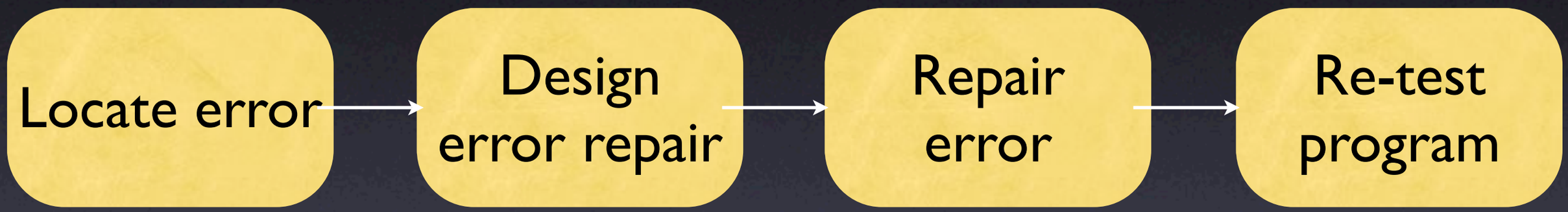
A Sample Program

```
$ sample 9 8 7
Output: 7 8 9
```

```
$ sample 11 14
Output: 0 11
```

How to Debug

(Sommerville 2004)



The Traffic Principle

T rack the problem

R eproduce

A utomate

F ind Origins

F ocus

I solate

C orrect

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T rack the problem

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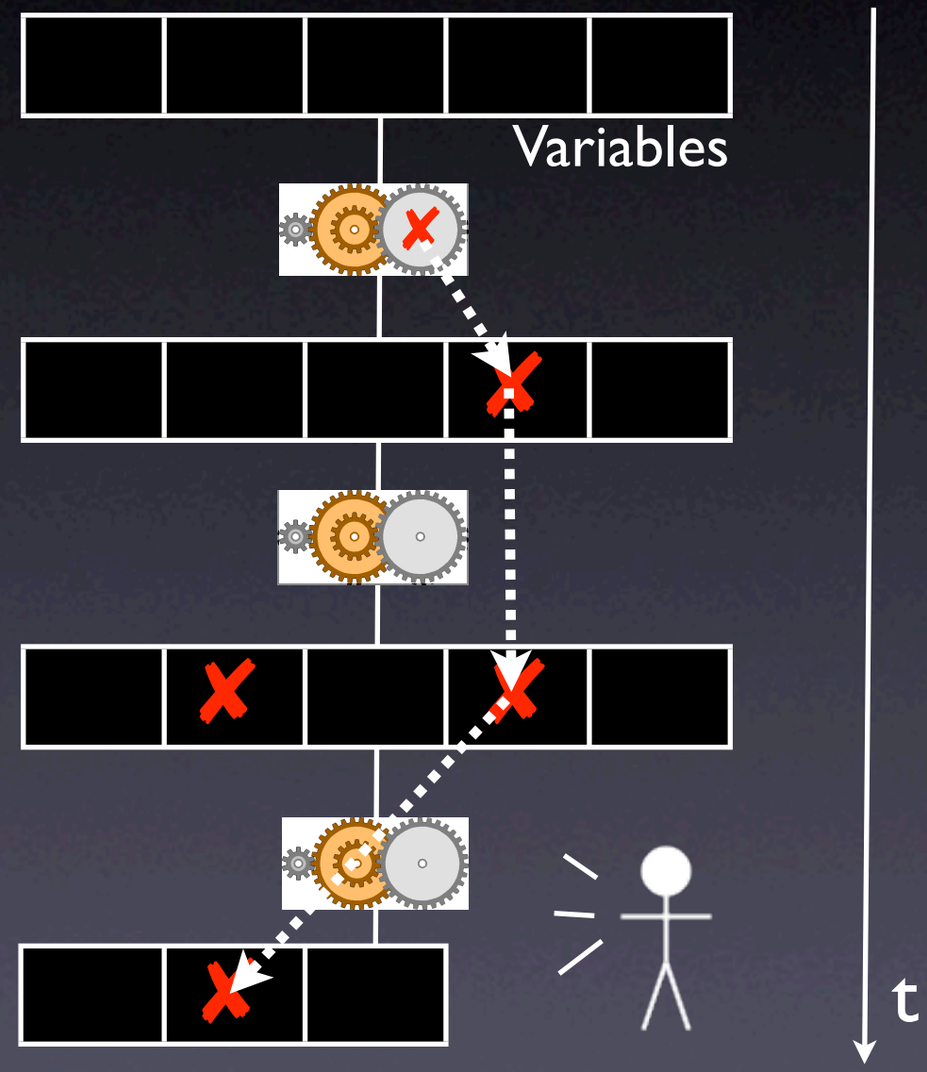
From Defect to Failure

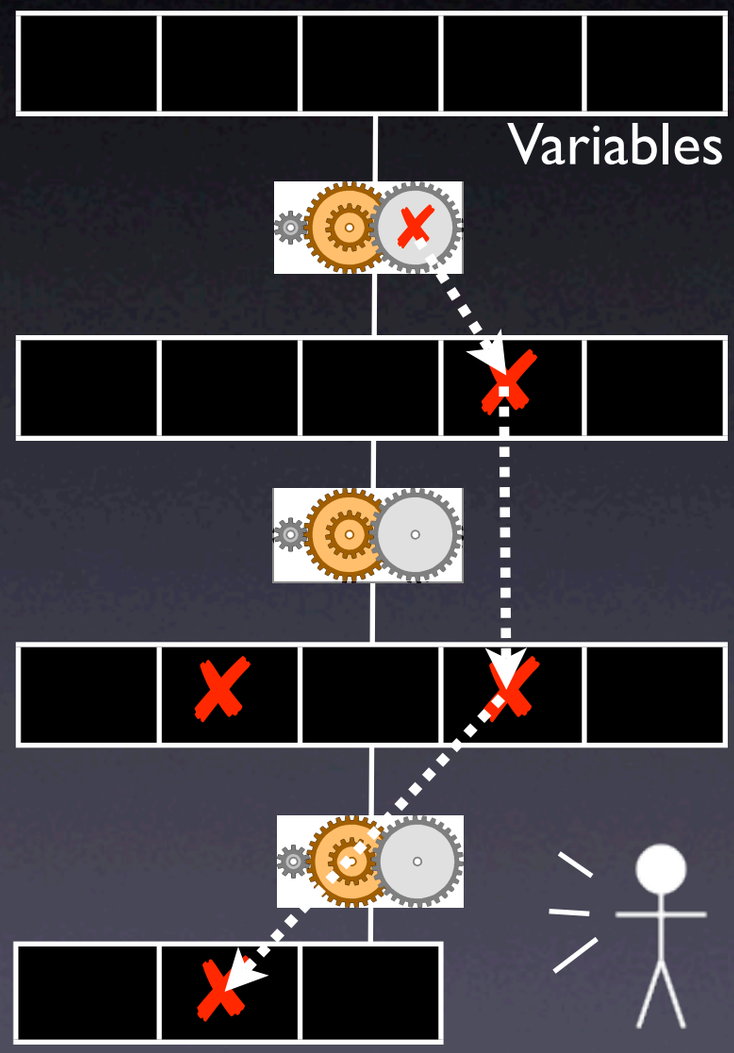
1. The programmer creates a *defect* – an error in the code.
2. When executed, the defect creates an *infection* – an error in the state.
3. The infection *propagates*.
4. The infection causes a *failure*.

This infection chain must be traced back – and broken.



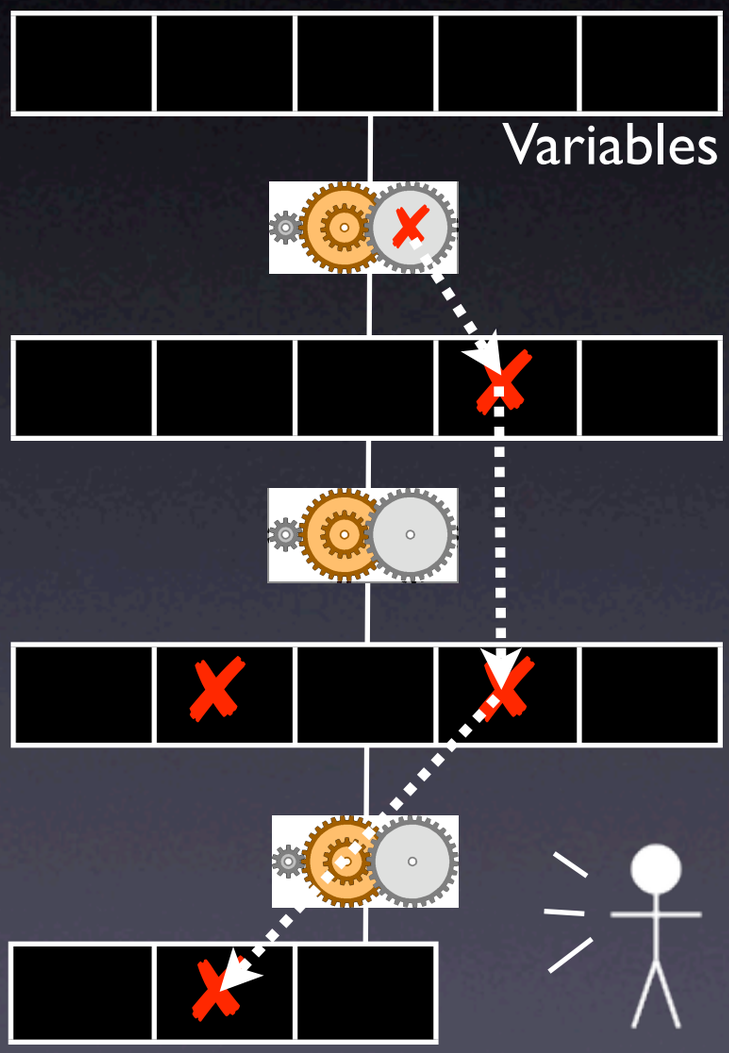
The Curse of Testing

- Not every defect causes a failure!
- *Testing can only show the presence of errors – not their absence.*
  (Dijkstra 1972)

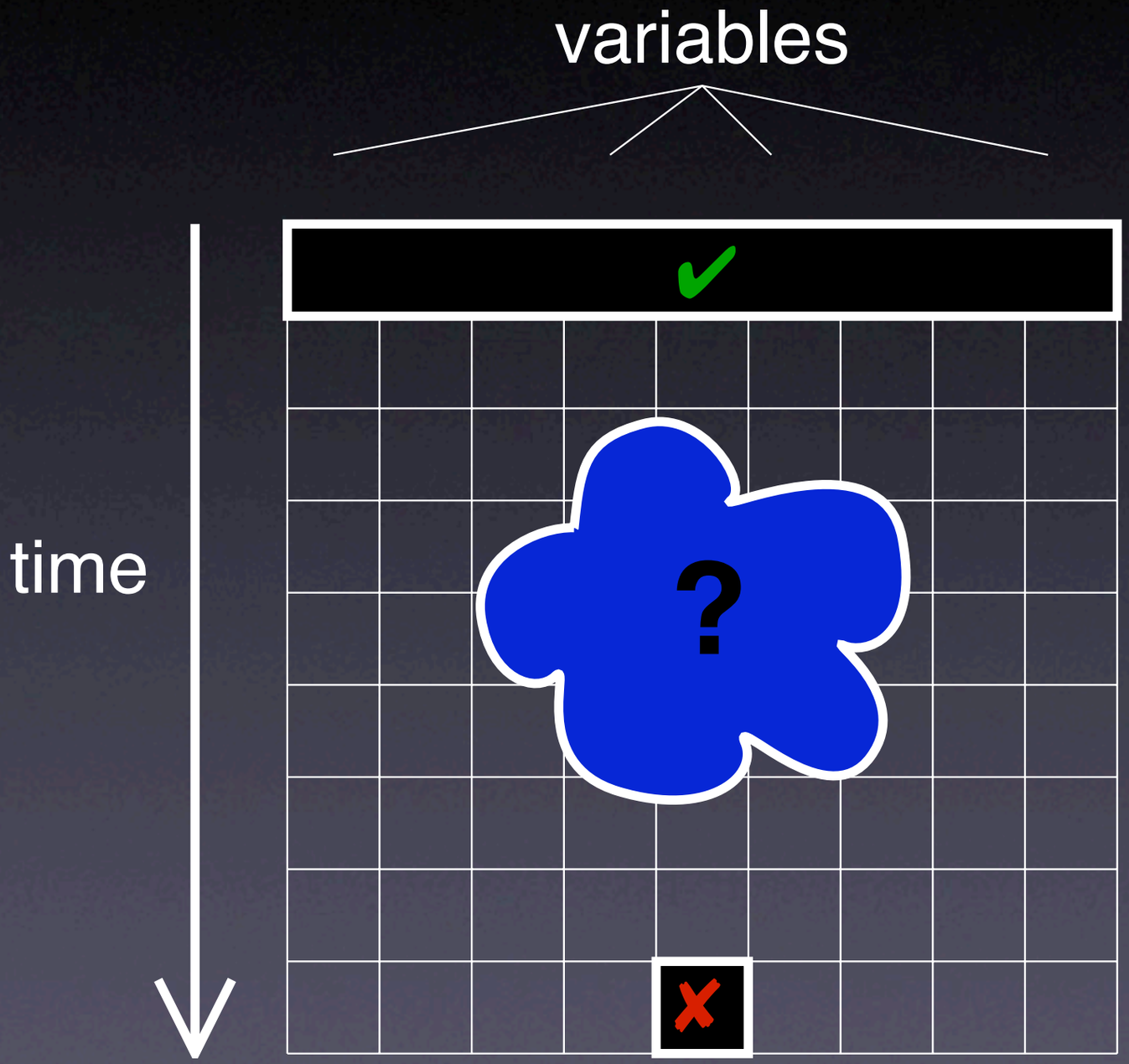


Debugging

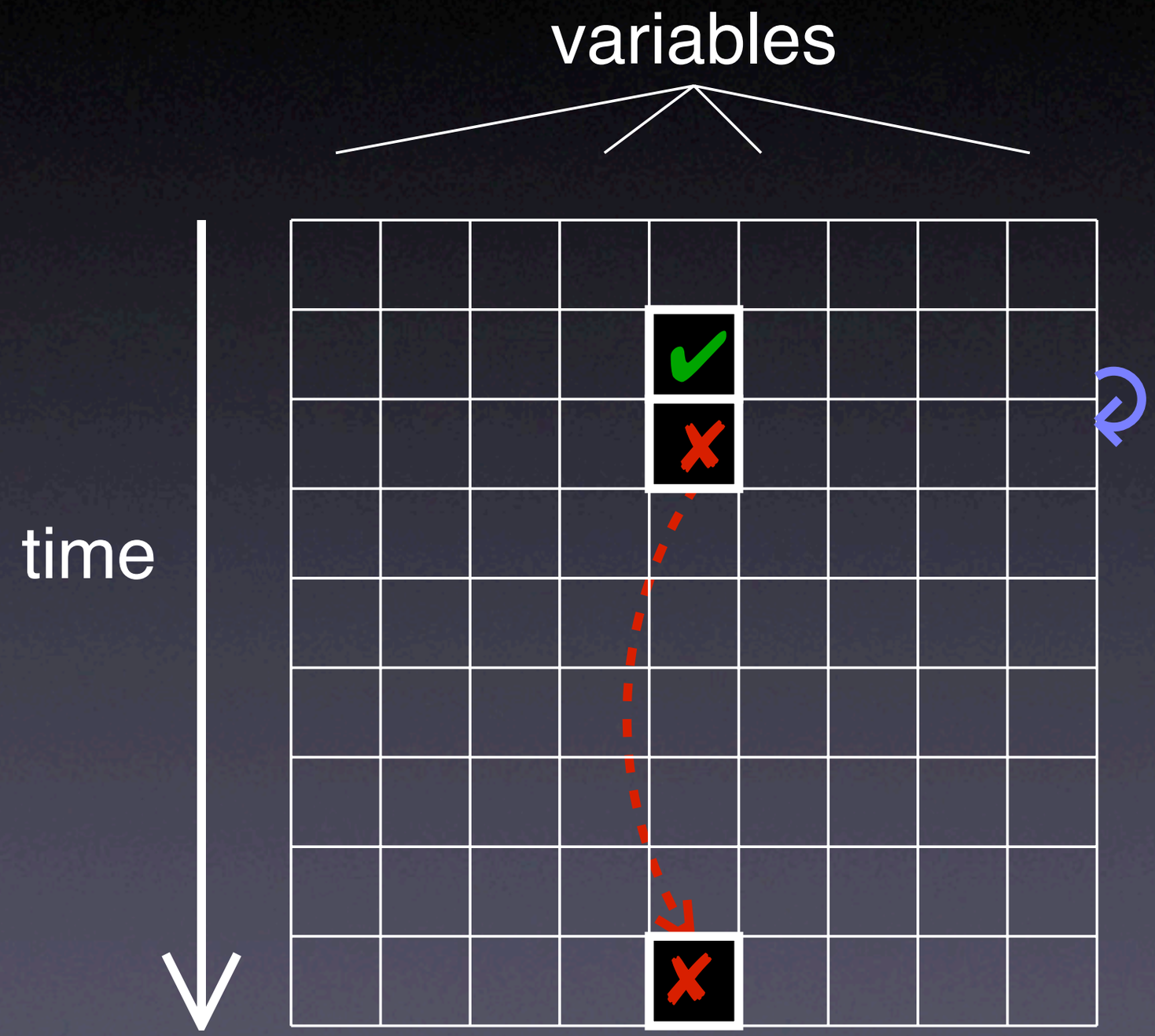
- Every *failure* can be traced back to some *infection*, and every *infection* is caused by some *defect*.
- *Debugging* means to *relate a given failure to the defect* – and to remove the defect.



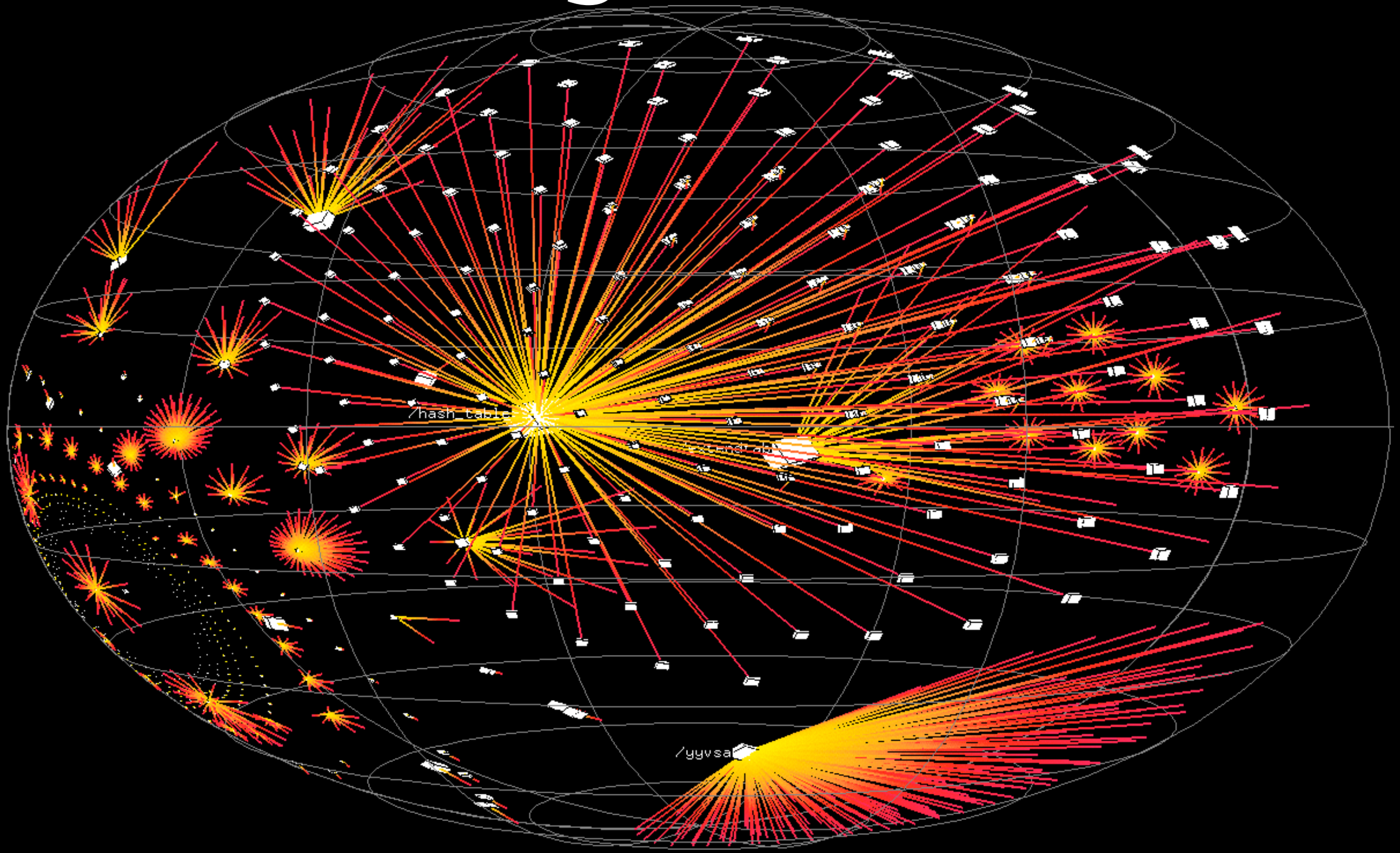
Search in Space + Time



The Defect



A Program State



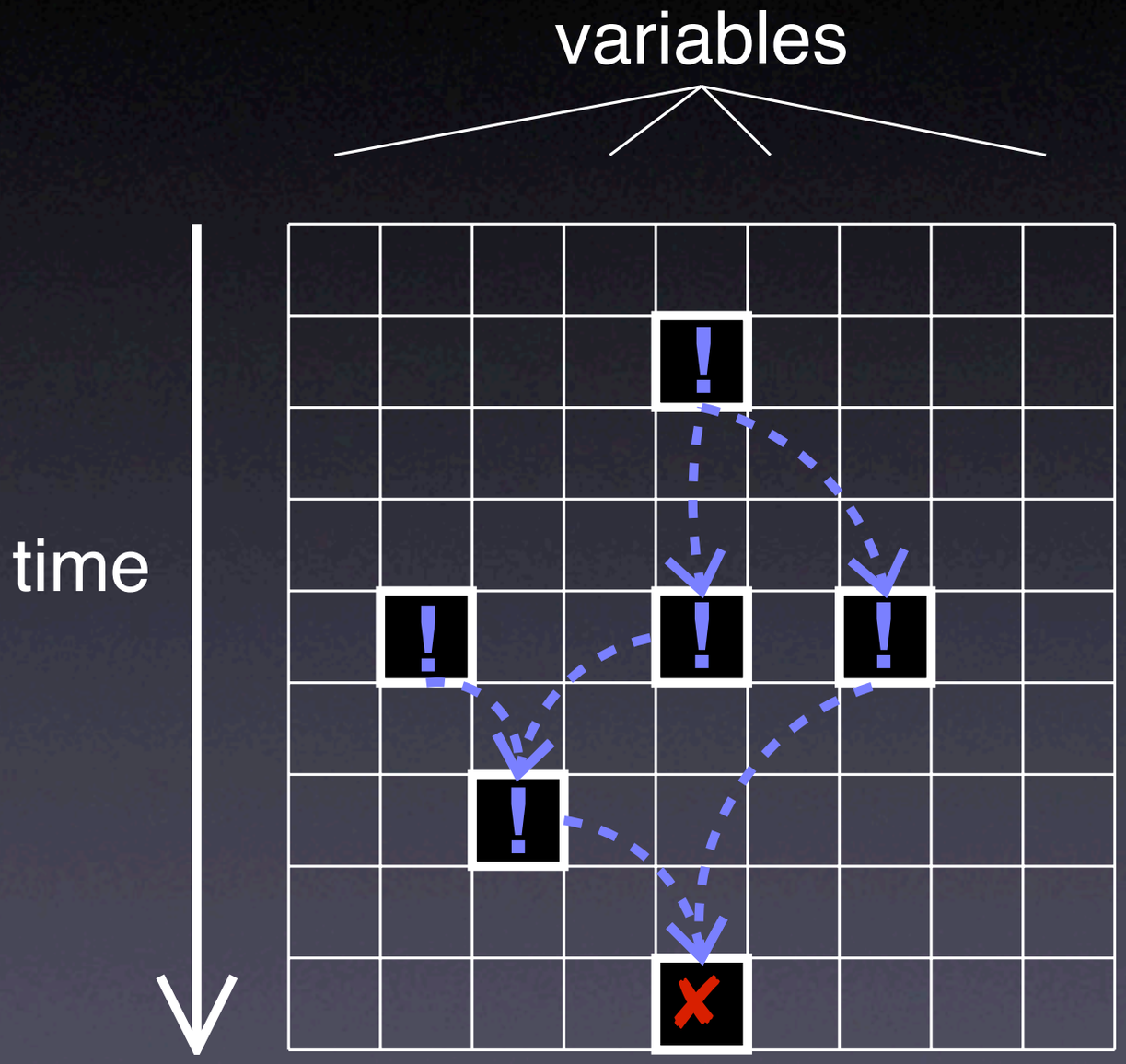
A Sample Program

```
$ sample 9 8 7
Output: 7 8 9
```

```
$ sample 11 14
Output: 0 11
```

```c
int main(int argc, char *argv[])
{
    int *a;
    int i;

    a = (int *)malloc((argc - 1) * sizeof(int));
    for (i = 0; i < argc - 1; i++)
        a[i] = atoi(argv[i + 1]);

    shell_sort(a, argc);

    printf("Output: ");
    for (i = 0; i < argc - 1; i++)
        printf("%d ", a[i]);
    printf("\n");

    free(a);

    return 0;
}
```

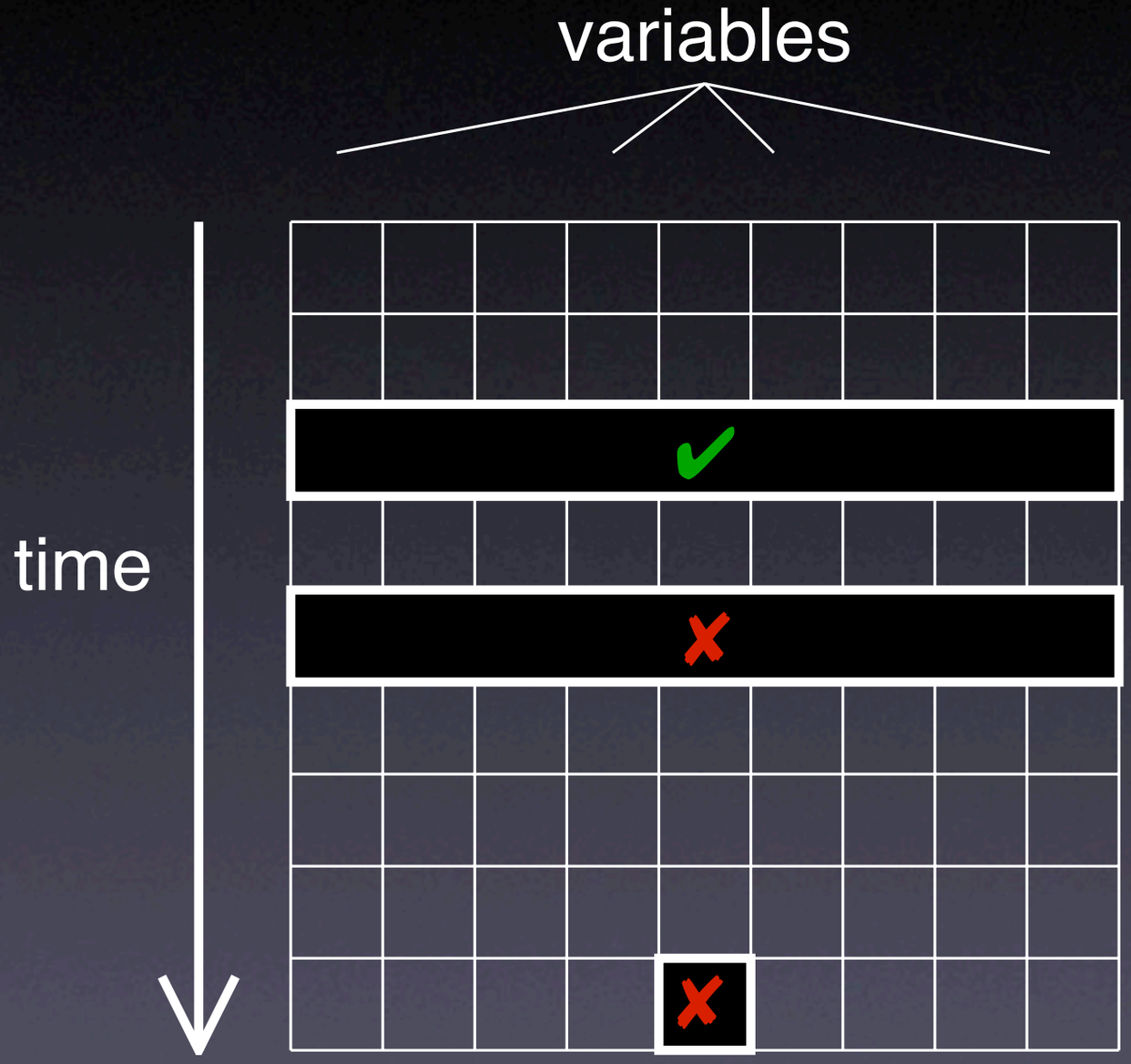
Find Origins



- The 0 printed is the value of `a[0]`. Where does it come from?
- Basic idea: Track or deduce value origins
- Separates *relevant* from *irrelevant* values
- We can trace back `a[0]` to `shell_sort`

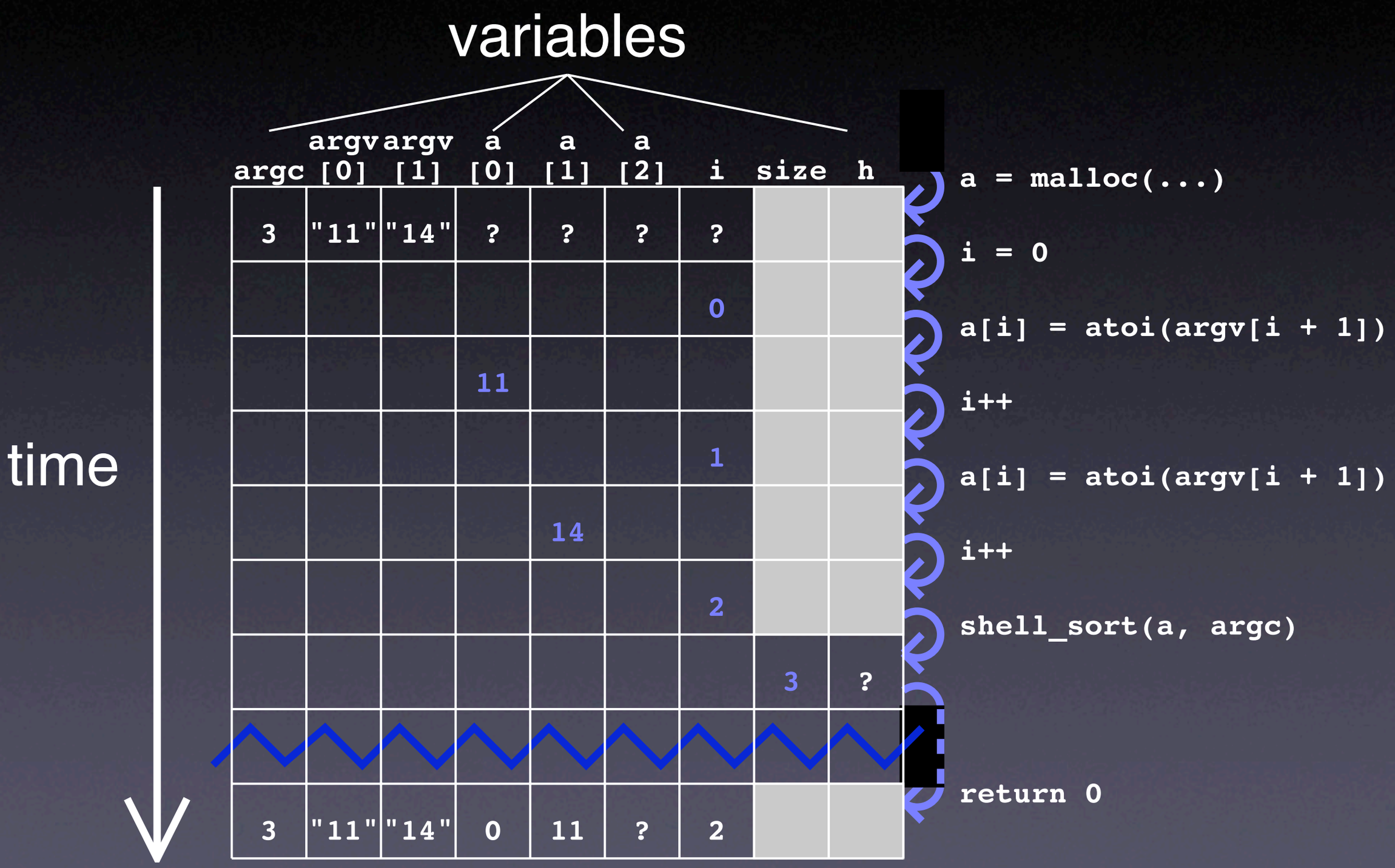
```
static void shell_sort(int a[], int size)
{
    int i, j;
    int h = 1;
    do {
        h = h * 3 + 1;
    } while (h <= size);
    do {
        h /= 3;
        for (i = h; i < size; i++)
        {
            int v = a[i];
            for (j = i; j >= h && a[j - h] > v; j -= h)
                a[j] = a[j - h];
            if (i != j)
                a[j] = v;
        }
    } while (h != 1);
}
```

Search in Time



- In shell_sort, the state must have become infected.
- Basic idea: Observe a transition from sane to infected.

Observing a Run



Specific Observation

```
static void shell_sort(int a[], int size)
{
    fprintf(stderr, “At shell_sort”);
    for (i = 0; i < size; i++)
        fprintf(stderr, “a[%d] = %d\n”, i, a[i]);
    fprintf(stderr, “size = %d\n”, size);
    int i, j;
    int h = 1;
    ...
}
```

```
$ sample 11 14
a[0] = 11
a[1] = 14
a[2] = 0
size = 3
Output: 0 11
```

The state is infected at the call of shell_sort!

Fixing the Program

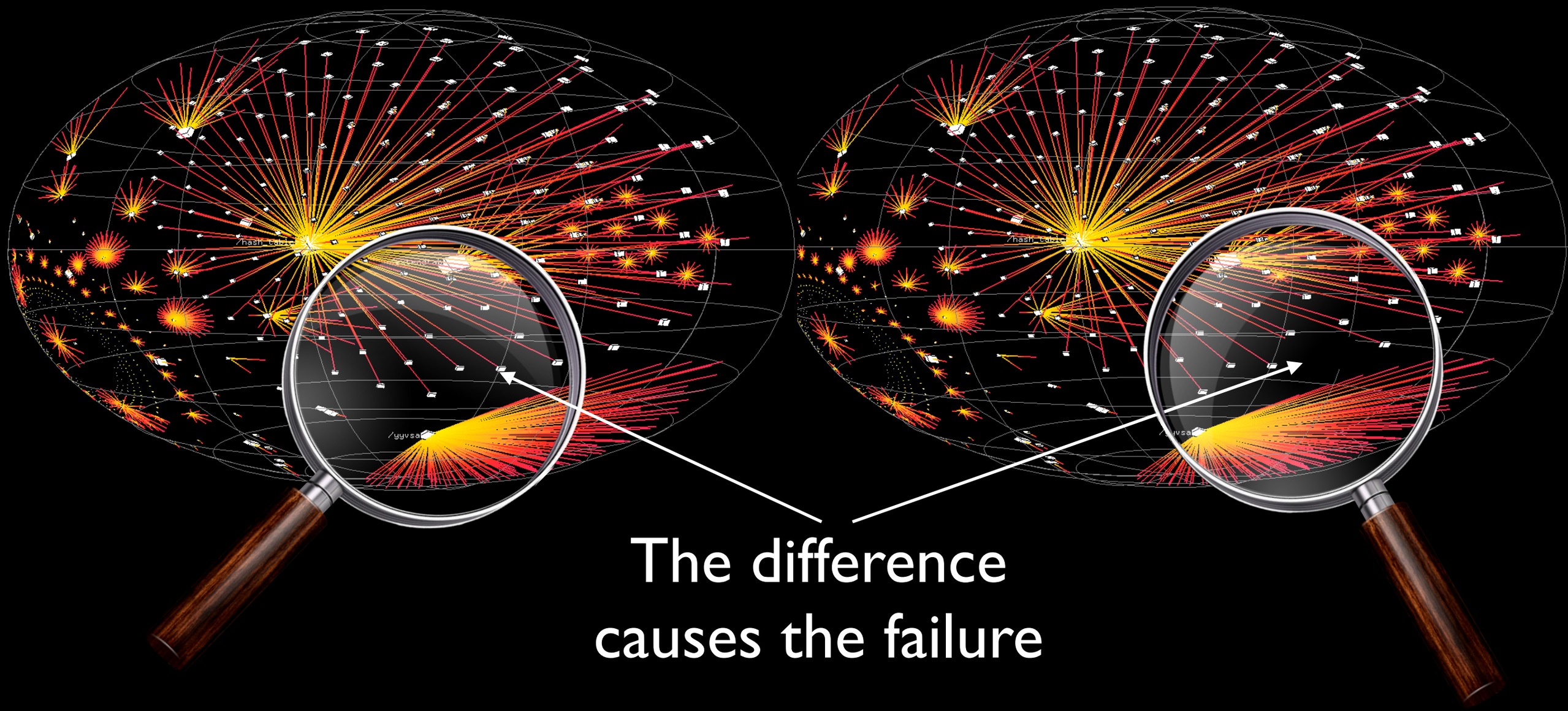
```
int main(int argc, char *argv[])
{
    int *a;
    int i;

    a = (int *)malloc((argc - 1) * sizeof(int));
    for (i = 0; i < argc - 1; i++)
        a[i] = atoi(argv[i + 1]);

    shell_sort(a, argc); 1);

    ...
}
```

```
$ sample 11 14
Output: 11 14
```

Finding Causes

Infected state

Sane state

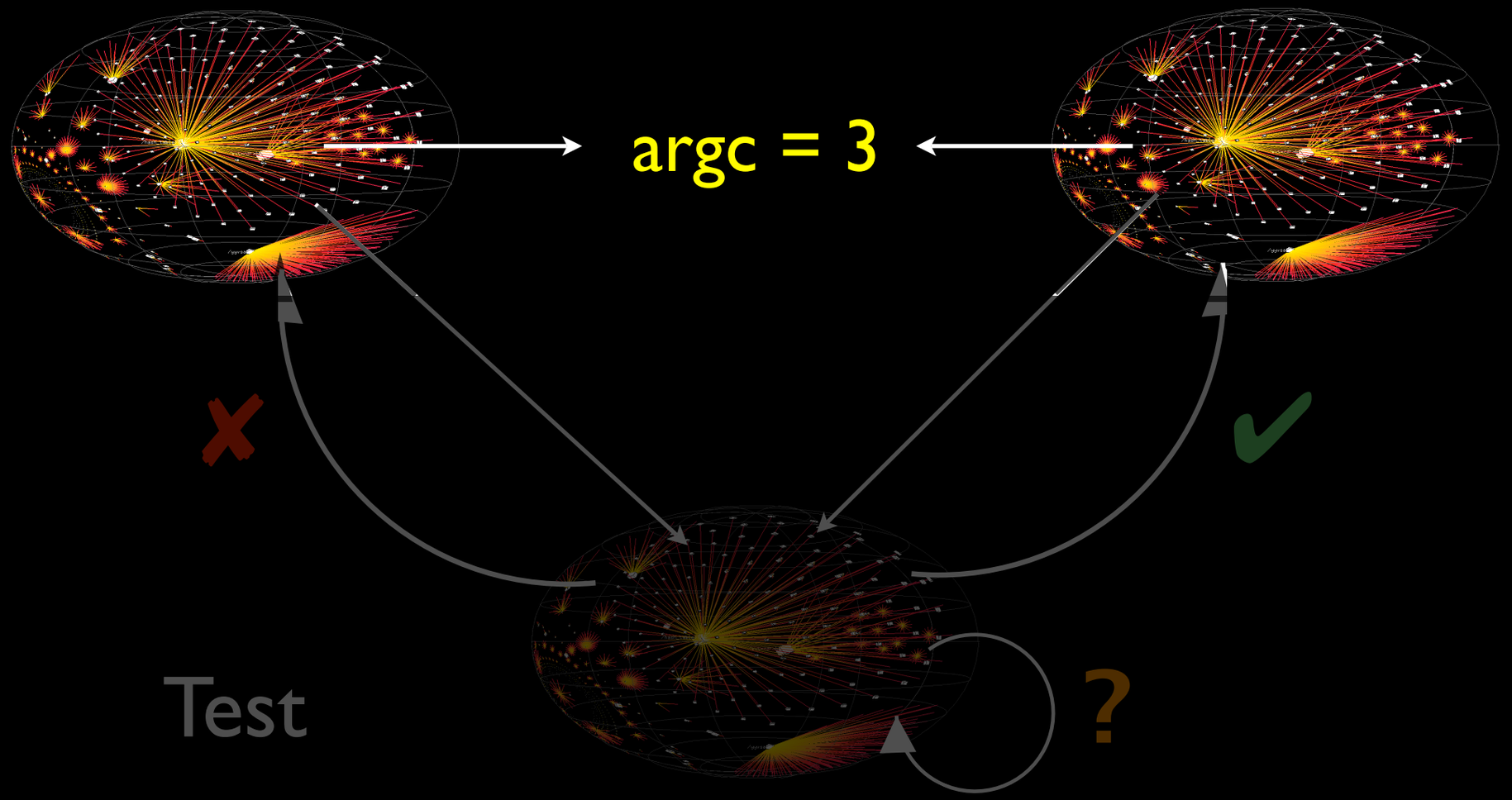


The difference
causes the failure

Search in Space

Infected state

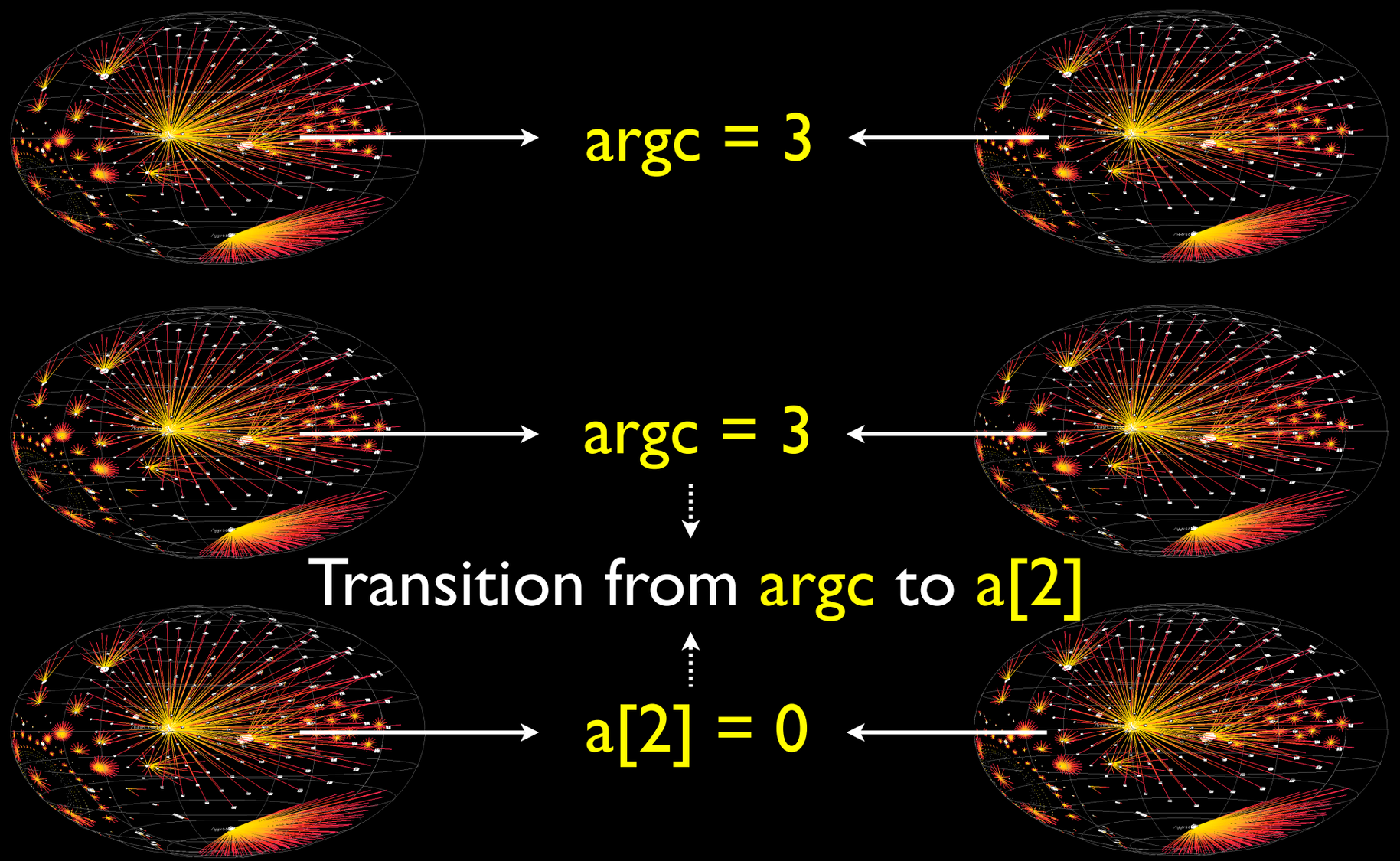
Sane state



Search in Time

Failing run

Passing run



```c
int main(int argc, char *argv[])
{
    int *a;

    // Input array
    a = (int *)malloc((argc - 1) * sizeof(int));
    for (int i = 0; i < argc - 1; i++)
        a[i] = atoi(argv[i + 1]);

    // Sort array
    shell_sort(a, argc);

    // Output array
    printf("Output: ");
    for (int i = 0; i < argc - 1; i++)
        printf("%d ", a[i]);
    printf("\n");

    free(a);
    return 0;
}
```

Should be argc - 1


AskIgor – Automated Debugging Service
http://www.askigor.org/
Google
AskIgor Status
All results
2004-08-12 10:30:54
Go!
Igor has finished debugging your program.
This is what happens in your program when it is invoked as "sample 11 14". (More info...)
1
Execution reaches line 35 of sample.c in main.
Since argc was 3,
local variable a[2] is now 0.
How did this happen?
2
Execution reaches line 18 of sample.c in shell_sort for the 2nd time.
Since a[2] was 0,
local variable v is now 0.
How did this happen?
3
Execution reaches line 15 of sample.c in shell_sort for the 2nd time.
Since v was 0,
local variable a[0] is now 0.
How did this happen?
4
Execution ends.
Since a[0] was 0,
the output now contains "0".
The program fails.
How did this happen?
Need more details? Select the effects you want to focus upon and Re-debug it! (More info...)
Plain wrong? Please check the failure symptoms as determined by Igor.
Any questions? See the AskIgor Forum!

Concepts

- A failure comes to be in three stages:
  1. The programmer creates a *defect*
  2. The defect causes an *infection*
  3. The infection causes a *failure* -- an externally visible error.
- Not every defect results in an infection, and not every infection results in a failure.

Concepts (2)

★ To debug a program, proceed in 7 steps:

T rack the problem
R eproduce
A utomate
F ind Origins
F ocus
I solate
C orrect

Concepts (3)

- ★ A variety of tools and techniques is available to *automate debugging*:
  - Program Slicing
  - Observing & Watching State
  - Asserting Invariants
  - Detecting Anomalies
  - Isolating Cause-Effect Chains