Causes and Effects

Andreas Zeller

bug.c

```c
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

Where is the error which causes this failure?

Locating Errors

An *error* is a deviation from what is *correct, right, or true:*

- *Input* (“The URL must be well-formed”)
- *Variables* (“link is zero”)
- *Statements* (“even(2) must return true”)

How do we know one of these is correct?

How can we say “The defect is here”?

Locating Causes

An aspect of the execution causes a failure if it can be altered such that the failure no longer occurs:

- *Input* (“11 14”)
- *Variables* (“argc = 2”)
- *Statements* (“Line 37”)

Note that a cause need not be an error!

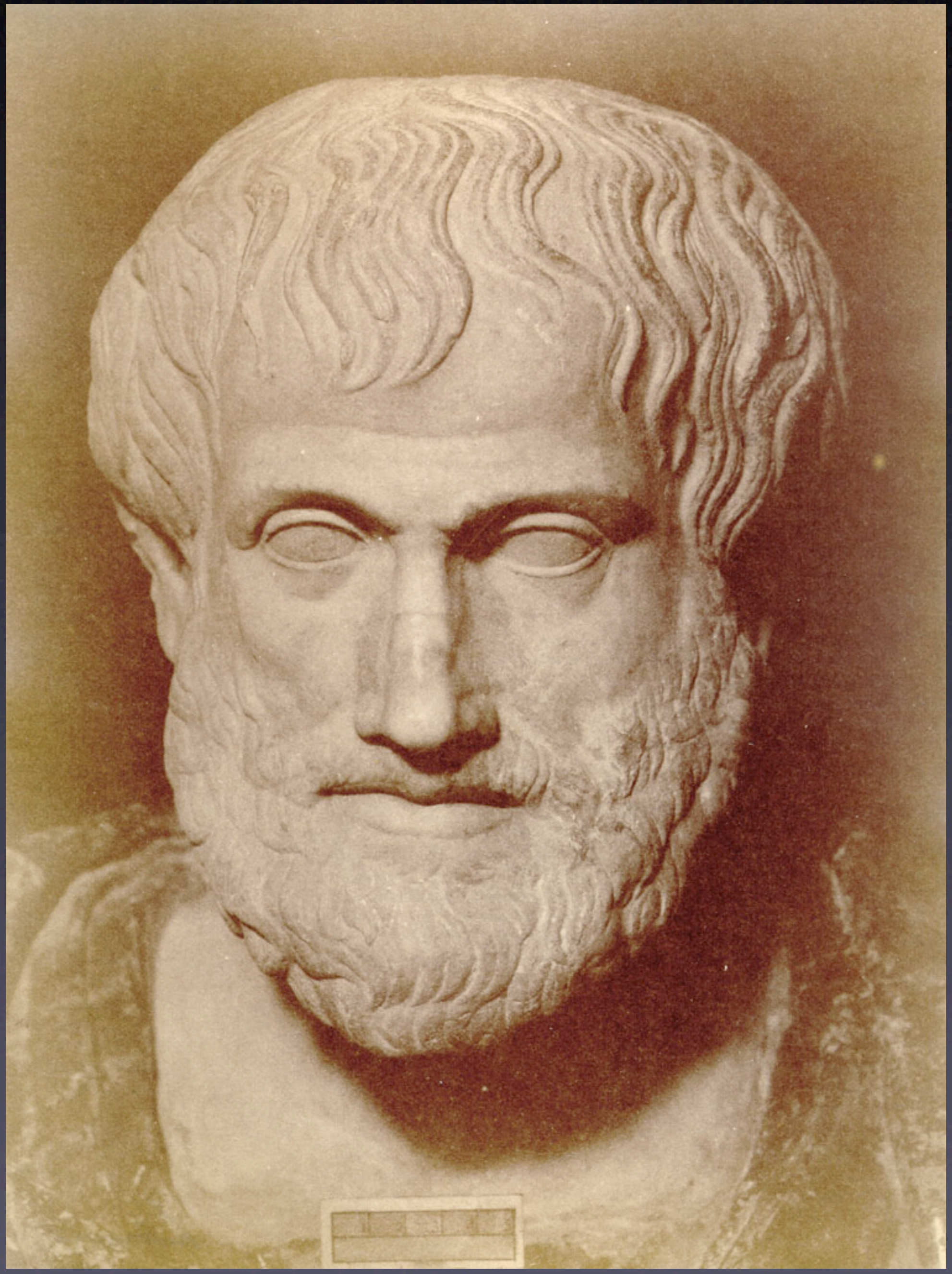
Causality

The notion of *causality* is deeply linked to fundamental questions of philosophy:

- What is it that makes things happen?
- Can we predict the future from causes?
- If everything has a cause, what is the ultimate cause of events in the past?

Aristotle

(384–322 BC)



Aristotle on Causality

Aristotle suggested four types of causes:

- The *material* of which things come
- The *form* which things have when they are perfected
- The *moving* cause or actual agent
- The *purpose* or *function* of such things

Example

Creating a silver chalice for a religious ceremony

- Material cause – the silver
- Formal cause – the design of the chalice
- Efficient cause – the silversmith
- Final cause – the religious ceremony

William of Ockham

(1288-1349)

Ockham on Causality

- The only way in which we can establish any causal connection between one thing and another is the observation that *when one of these occurs, the other also occurs at the same time and at or near the same place*.
- This is *the only way* to establish causality

David Hume

(1711–1776)

Hume on Causality

- When we see that two events always occur together, we tend to form an expectation that when the first occurs, the second will soon follow.
- This constant conjunction and the expectation thereof is all that we can know of causation, and all that our idea of causation can amount to.

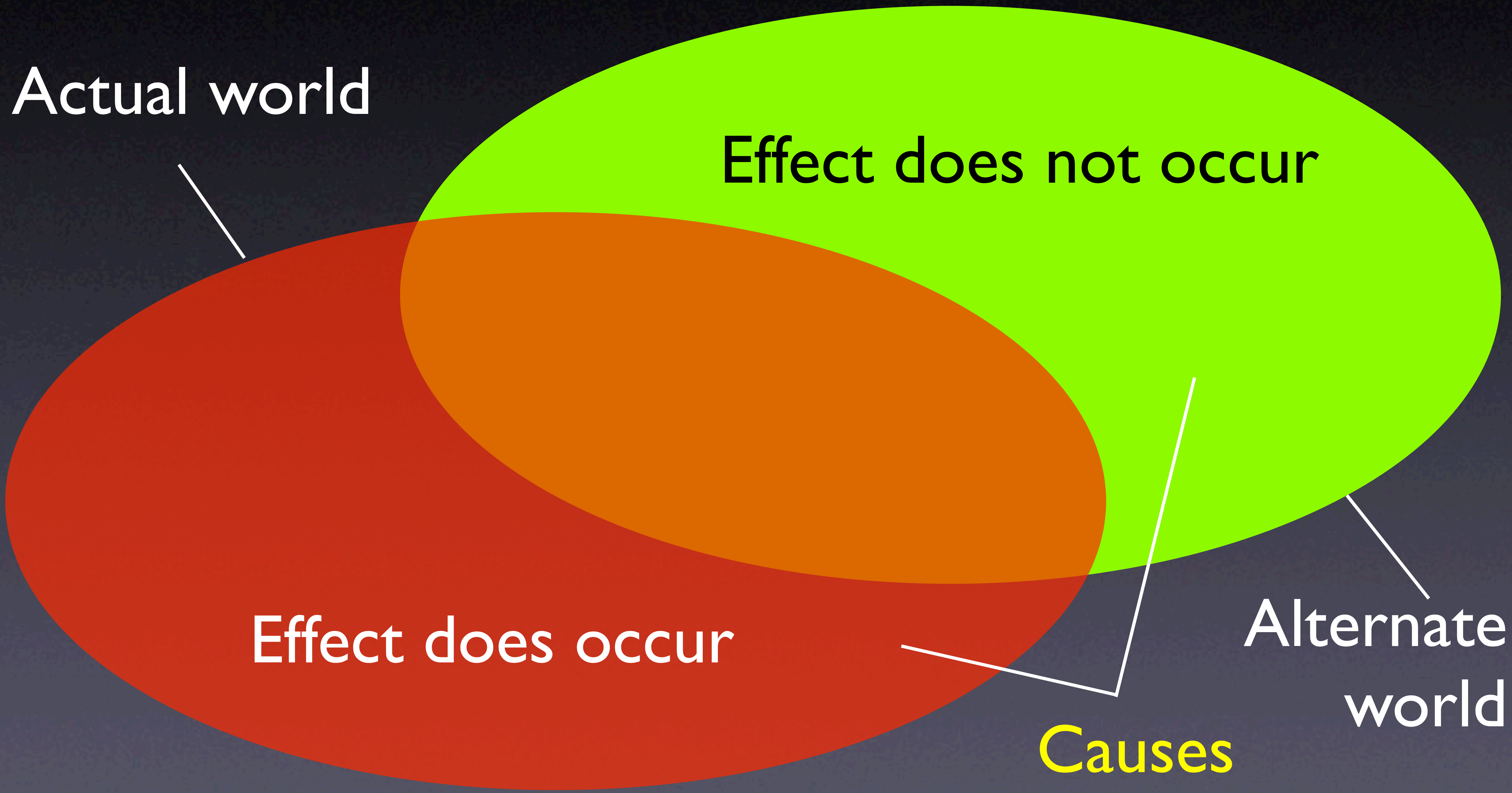
Causality as Illusion

- Just because the sun has risen every day since the beginning of the Earth does not mean that it will rise again tomorrow.
- Bertrand Russell: "causation = superstition"

Counterfactuals

- We may define a *cause* to be an object followed by another, and where all the objects, similar to the first, are followed by objects similar to the second. Or, in other words, where, *if the first object had not been, the second never had existed.* (Hume, 1748)
- Hume never explored this alternative

Causality



Actual world

Effect does not occur

Effect does occur

Causes

Alternate world

bug.c

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

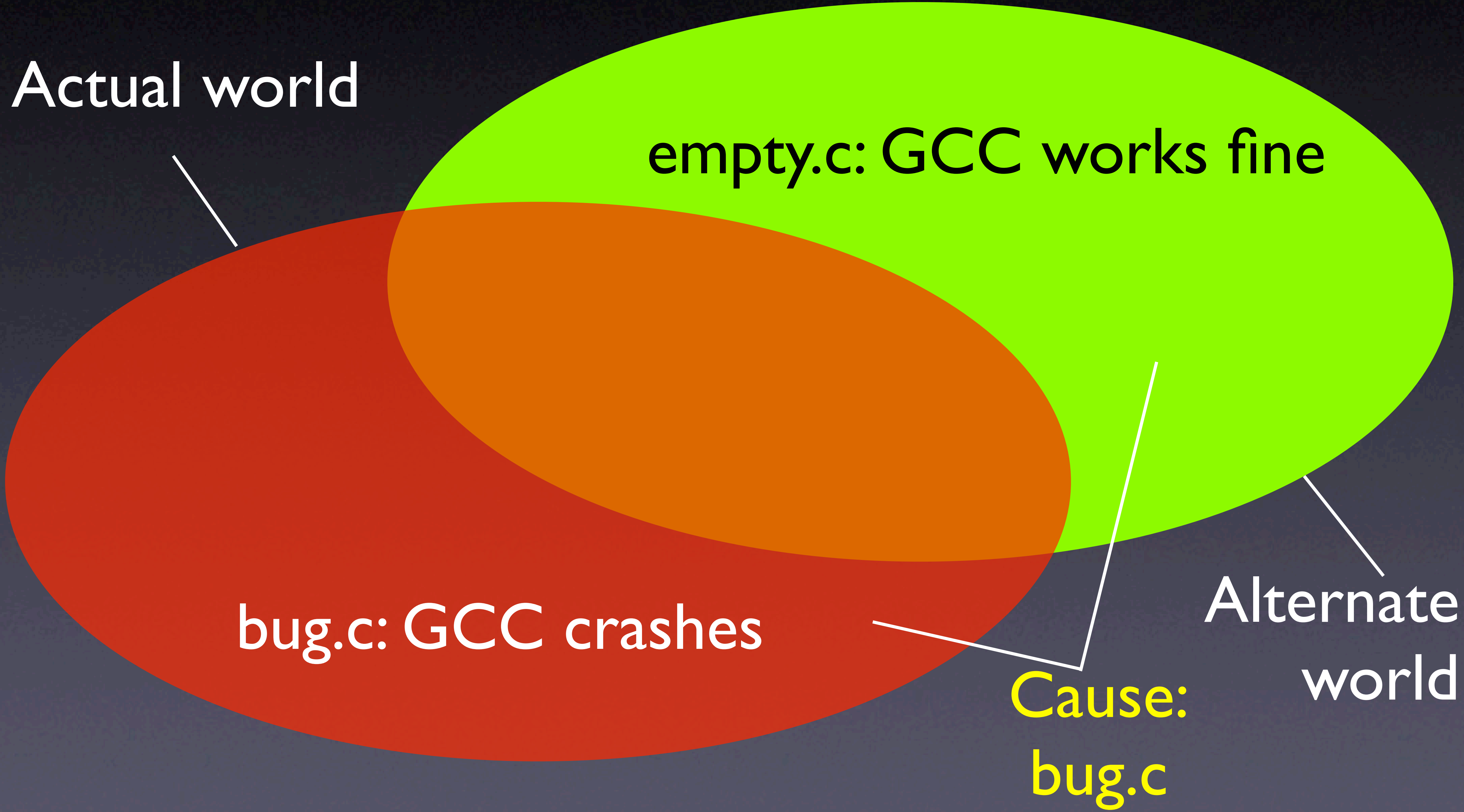
empty.c

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

✓

Causes as Differences



Actual world

empty.c: GCC works fine

bug.c: GCC crashes

Cause:
bug.c

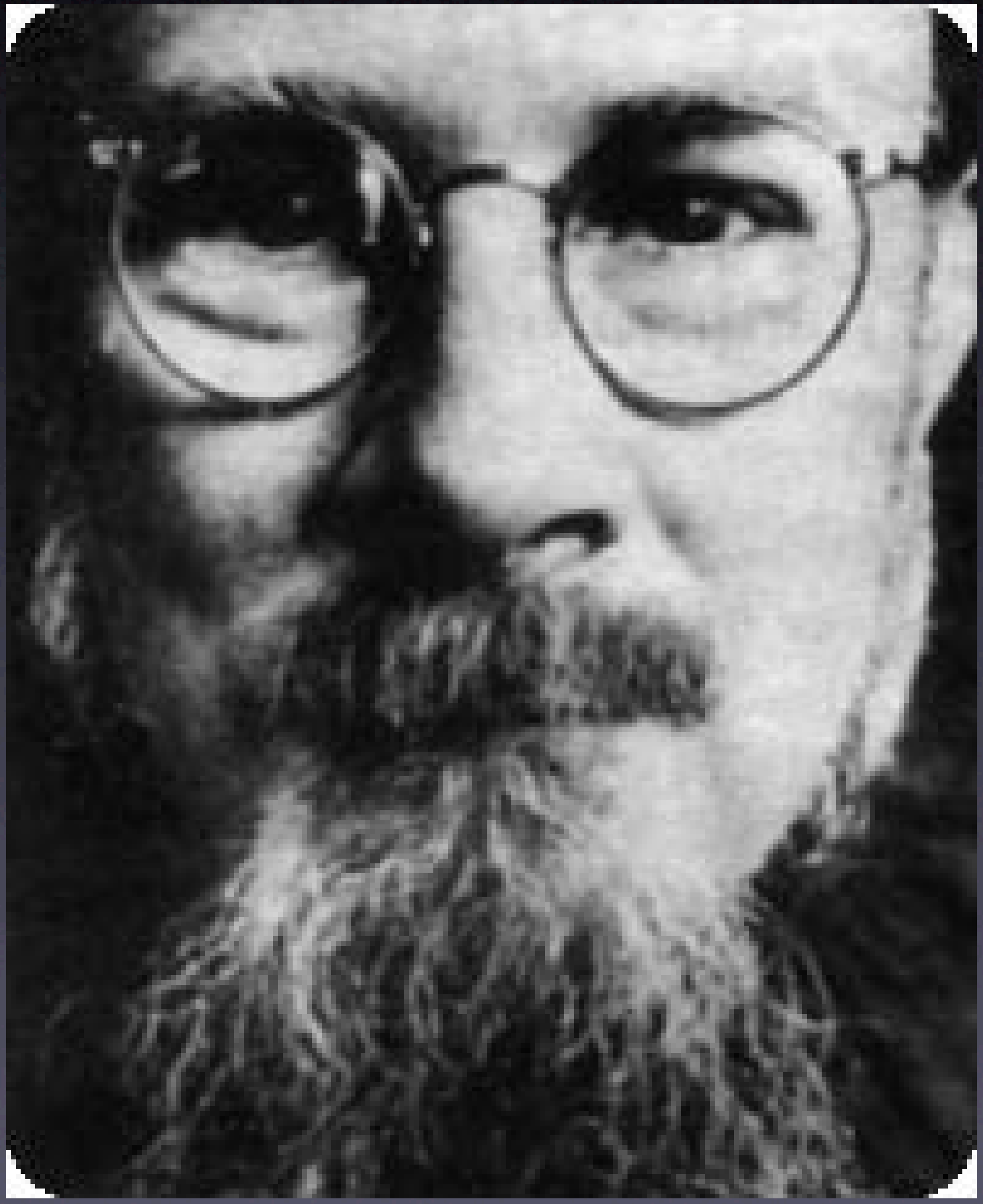
Alternate
world

More possible causes

GCC code	invocation	me
Linux	electricity	oxygen

David Lewis

(1941–2001)



Lewis on Causation

- $C \circ\!\!\rightarrow E$ means “If C had been the case, E would have been the case”
- C *causes* E if $C \circ\!\!\rightarrow E$ and $\neg C \circ\!\!\rightarrow \neg E$ hold.
- $C \circ\!\!\rightarrow E$ holds if some C-world where E holds is *closer to the actual world* than is any C-world where E does not hold.

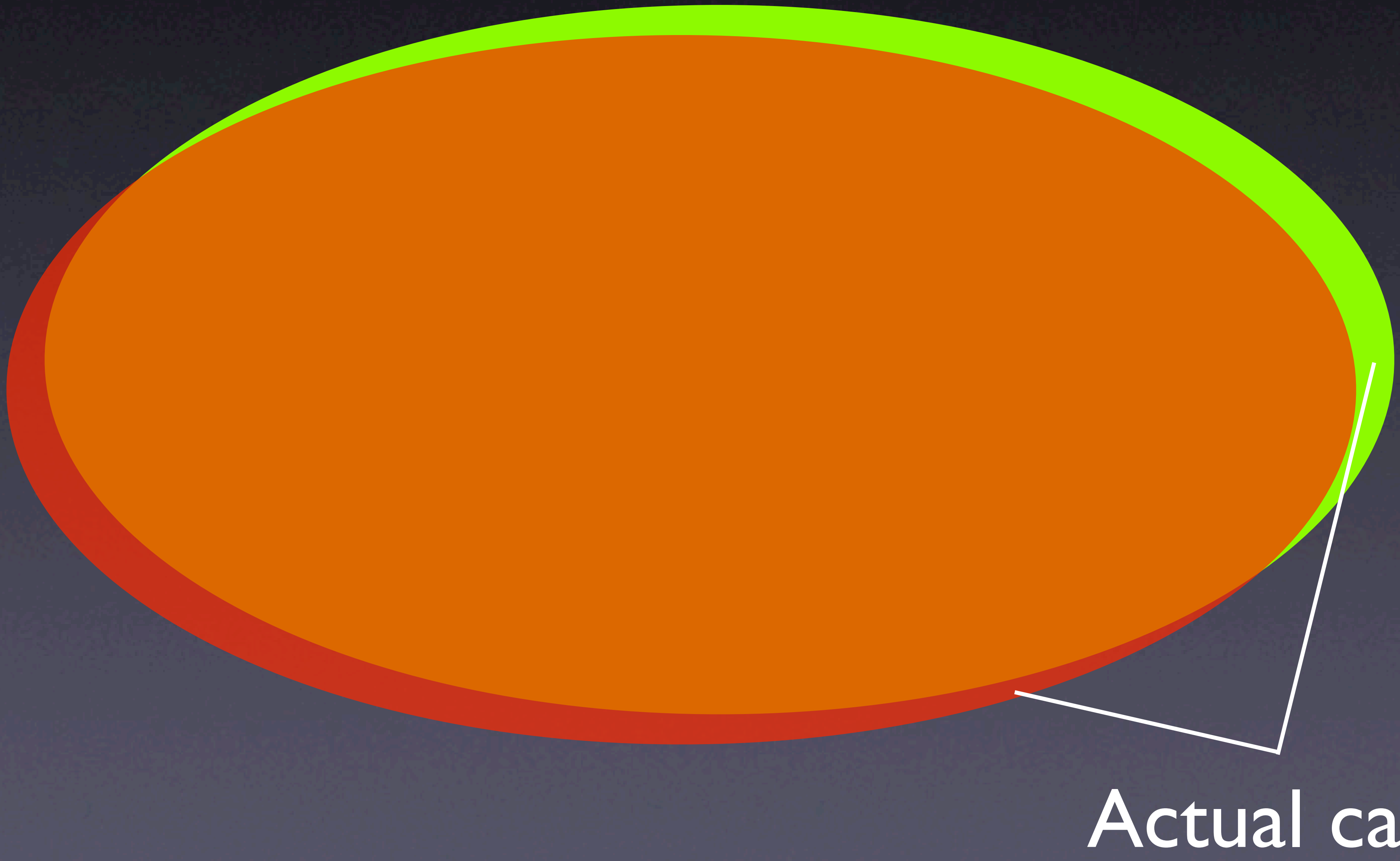
Possible Worlds

$C \circ\!\!\rightarrow E$ holds if some C-world where E holds is *closer to the actual world* than is any C-world where E does not hold.

- A world with an alternate GCC input is closer than a world without oxygen
- A world with GCC fixed may be closer than a world with an alternate GCC input

Actual Causes

“The” cause (*actual cause*) is a *minimal difference*



Isolating Causes

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

Isolating Causes

```
double bug(double z[], int n) {
    int i, j;

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    }
    return z[n];
}
```

✓

Isolating Causes

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
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    }
    return z[n];
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```

Isolating Causes

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        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

Actual cause narrowed down

Isolating Causes

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

✓

Isolating Causes

```
double bug(double z[], int n) {
    int i, j;

    i = 0;
    for (j = 0; j < n; j++) {
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    }
    return z[n];
}
```

Isolating Causes

```
double bug(double z[], int n) {
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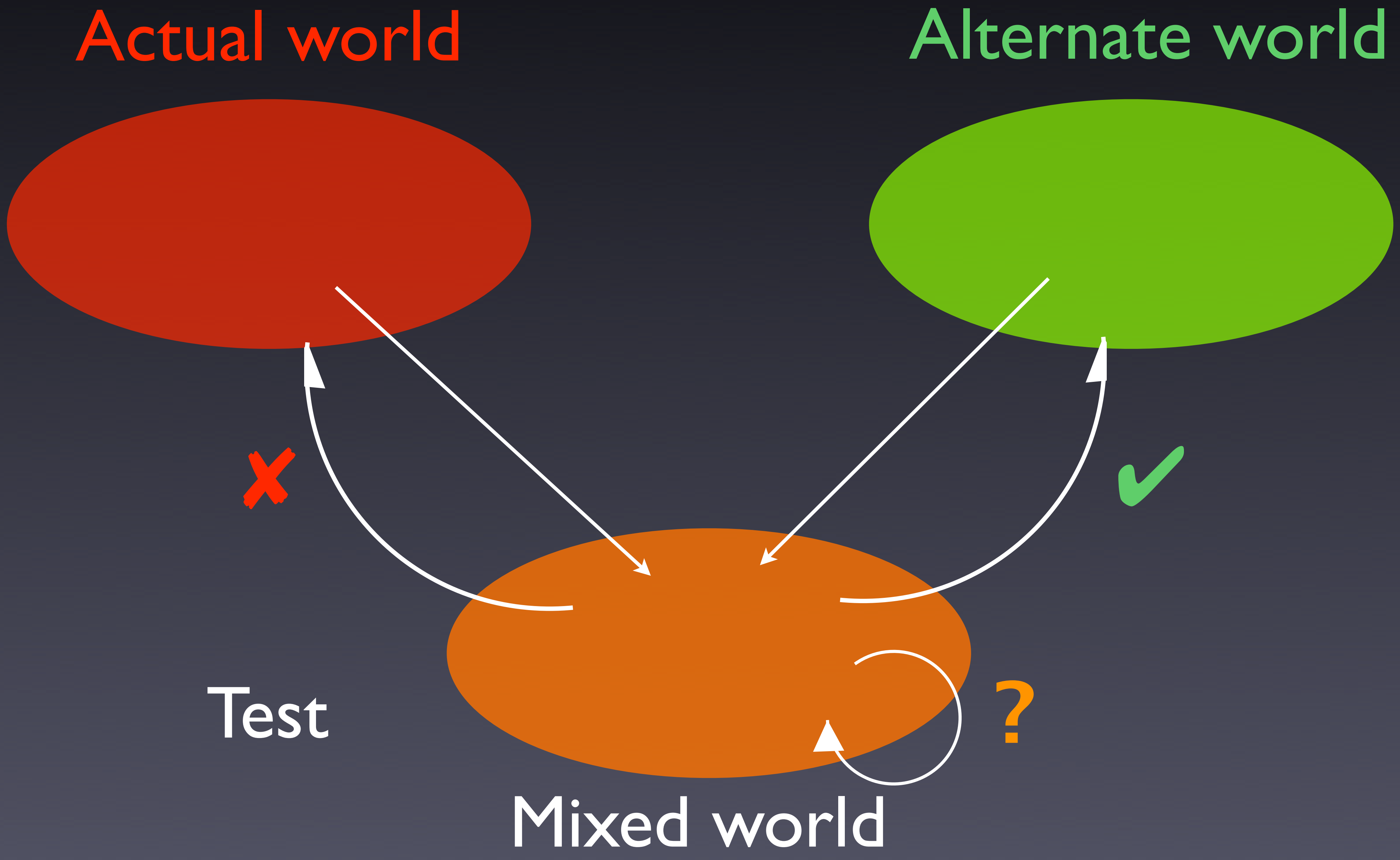
        i = i + j + 1;
        z[i] = z[i] * (z[0] + 1.0);
    }
    return z[n];
}
```

Actual cause of the GCC crash

Isolating Causes



Actual world

Alternate world

✘

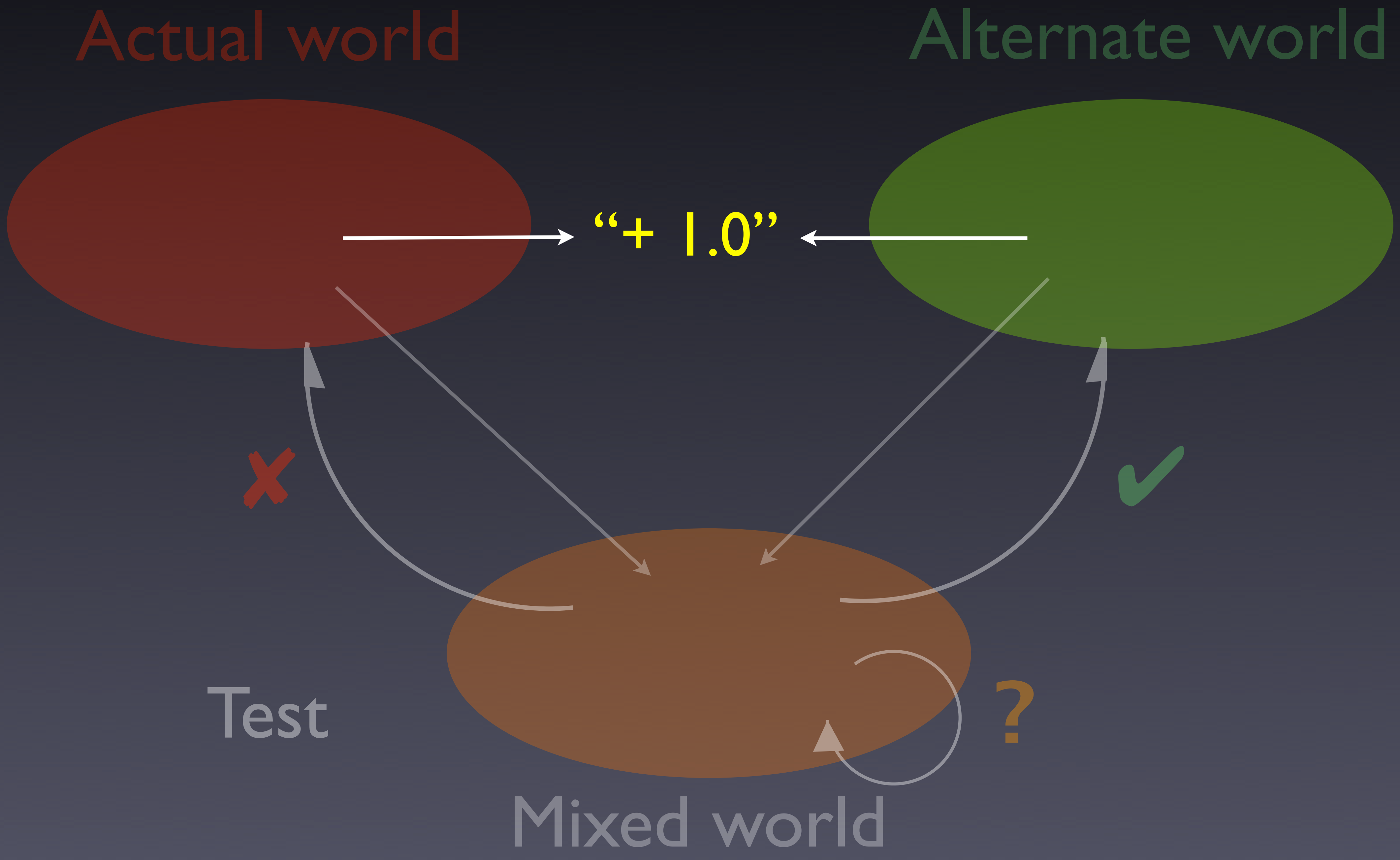
✔

Test

?

Mixed world

Isolating Causes



Search Space

The choice of an *initial set of differences* determines the search space for causes:

- the input (data, configuration, …)
- the program state
- the program code

Sets a *common context* between worlds

Search Space

Input	State	Code
OS	Compiler	Processor
FBI	E.T.	*Them!*

Ockham's Razor

- Whenever you have competing theories for how some effect comes to be, *pick the simplest.*

Ockham’s Razor

In our context:

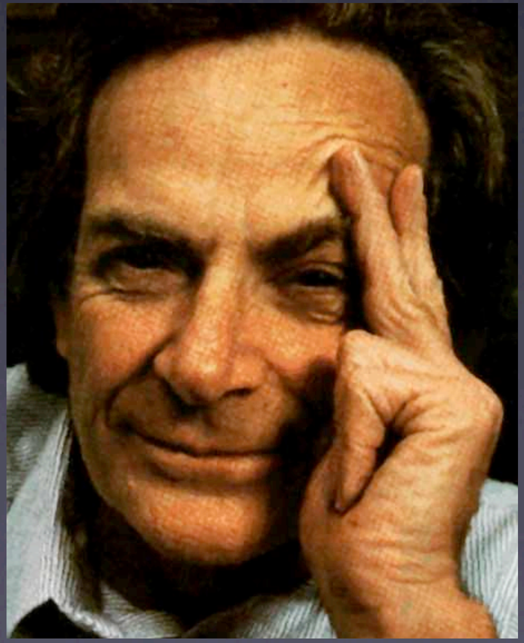
- Whenever you have the choice between multiple causes, *pick the one whose alternate world is closer.*

Search Space

Input	State	Code	close
OS	Compiler	Processor	far away
FBI	E.T.	*Them!*	far out

Hanlon’s Razor

- Never explain by malice which is adequately explained by stupidity



Verifying Causes

```
$ ./psharp db.p#
.psharprc: 37: no such interpreter
.psharprc: 37: bailing out
Segmentation fault
```

Do we know the configuration in .psharprc causes the failure?

Causes and Effects

To prove causality, one must show that

- the effect occurs when the cause occurs
- the effect does *not* occur when the cause does not.

This is *the only way* to prove causality

Verifying Causes

```
$ mv ~/.psharprc ~/.psharprc.orig
$ ./psharp db.p#
Segmentation fault
```

So it wasn’t the configuration after all

Verifying Causes

```
$ ./psharp db.p#
.psharprc: 37: no such interpreter
.psharprc: 37: bailing out
Segmentation fault
```

Avoid *post hoc ergo propter hoc* fallacies

Verifying Causes

```
a = compute_value();
printf("a = %d\n", a);
```

```
a = 0
```

Is variable *a* zero?

```
a = compute_value();
a = 1;
printf("a = %d\n", a);
```

```
a = 0
```

What’s going on?

```
double a;
a = compute_value();
a = 1;
printf("a = %d\n", a);
```

```
a = 0
```

What’s going on?

```
double a;
a = compute_value();
printf("a = %f\n", a);
```

```
a = 3.14…
```

What’s going on?

```
double a;
a = compute_value();
printf("a = %f\n", a);
```

We have isolated the format "%d"
as the actual failure cause

Preemption

Billy and Suzy throw rocks at a bottle. Suzy throws first so that her rock arrives first and shatters the glass. Without Suzy's throw, Billy's throw would have shattered the bottle.

- *Does Suzy’s throw cause the shattering?*

Alteration

- C *influences* E if C can be *altered* to C’ such that E’ occurs instead of E (Lewis; 1999)
- If Suzy had not thrown the stone, the bottle would have shattered in a different manner
- Therefore, Suzy’s throw *influenced* and caused the original shattering

What's the Failure?

- Every failure has some aspects that we consider relevant
- This choice influences the search for causes
- If the *entire state* of the program is part of the failure, we get very *detailed causes*
- If just one aspect is relevant, we get simpler causes – sometimes too simple

Concepts

- A *cause* is an event preceding another event (the *effect*) without which the effect would not have occurred
- A cause can be seen as a *difference* between a world where the effect occurs and a world where it does not
- An *actual* cause means a *minimal difference*

Quiz

If *C* is a cause and *E* is its effect, then *C* must precede *E*.

☒ yes   □ no

Quiz

If *C* is a circumstance that causes a failure, then it is possible to change *C* such that the failure no longer occurs.

☒ yes □ no

Quiz

If some cause *C* is an actual cause, then altering *C* induces the smallest possible difference in the effect.

□ yes ☒ no

Quiz

Every failure cause implies a possible fix.

☒ yes □ no

Quiz

For every failure, there is exactly one actual cause.

□ yes ☒ no

Quiz

For every defect, there is exactly one correction.

☒ yes □ no

Quiz

A failure cause can be determined without executing the program.

□ yes ☒ no

Quiz

A failure is the difference to the closest possible world in which the cause does not occur.

□ yes ☒ no

Quiz

If I observe two runs (one passing, one failing) with a minimal difference in input, then I have found an actual failure cause.

☒ yes　　□ no

Quiz

A minimal and successful correction proves that the altered code was the actual failure cause.

☒ yes □ no

Quiz

Increasing the common context between the possible worlds results in smaller causes.

□ yes ☒ no