The Scientific Method

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Projects

- 1–3 done individually
- 4 may be done in pairs (details later)

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Bug of the ~~Week~~ Year

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Everything typed into T-Mobile G1 was taken as a shell command (i.e. “reboot”)

http://crave.cnet.co.uk/mobiles/0,39029453,49299782,00.htm

Recent **T-Mobile G1** update has caused a peculiar side-effect that's proving rather

A Sample Program

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

$ sample 11 14
Output: 0 11
```

Where's the *error* that *causes* this failure?

Errors

What's the error in the sample program?

- An *error* is a deviation from what's correct, right, or true. (IEEE glossary)

To prove that something is an error, we must *show the deviation:*

- *Simple* for failures, *hard* for the program

Where does sample.c deviate from – what?

Causes and Effects

What's the cause of the sample failure?

- The *cause* of any event ("effect") is a preceding event without which the effect would not have occurred.

To prove causality, one must show that

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

Establishing Causality

In natural and social sciences, causality is often hard to establish.

- Did drugs cause the death of Elvis?
- Does CO_2 production cause global warming?
- Did Saddam Hussein cause the war in Iraq?

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Repeating History

- To determine causes formally, we would have to *repeat history* – in an alternate world that is as close as possible to ours.
- Since we cannot repeat history, we have to *speculate* what *would* have happened.
- Some researchers have suggested to drop the concept of causality altogether

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Repeating Runs

In computer science, we are luckier:

- Program runs can be controlled and repeated at will
  (well, almost: physics can't be repeated)
- Abstraction is kept to a minimum – the program is the real thing.

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"Here's the Bug"

- Some people are good at guessing causes!
- Unfortunately, intuition is hard to grasp:
  - Requires *a priori knowledge*
  - Does not work in a systematic and reproducible fashion
  - In short: *Intuition cannot be taught*

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The Scientific Method

- The *scientific method* is a general pattern of how to find a *theory* that explains (and predicts) some aspect of the universe
- Called "scientific method" because it's supposed to summarize the way that (experimental) scientists work

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The Scientific Method

1. Observe some aspect of the universe.
2. Invent a *hypothesis* that is consistent with the observation.
3. Use the hypothesis to make *predictions*.
4. Tests the predictions by experiments or observations and modify the hypothesis.
5. Repeat 3 and 4 to refine the hypothesis.

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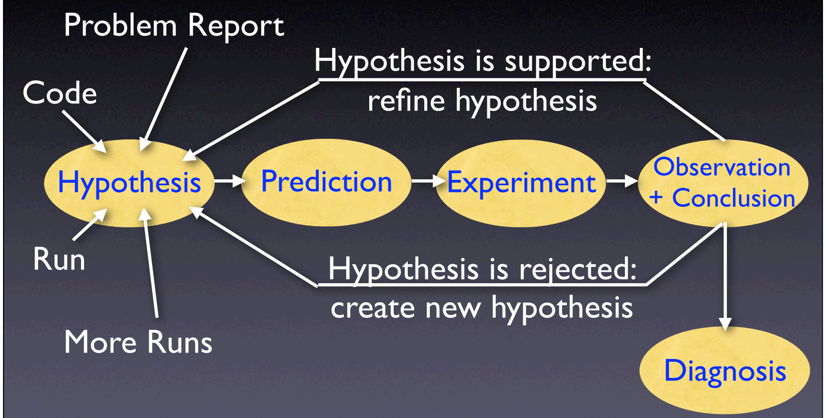
A Theory

- When the hypothesis explains all experiments and observations, the hypothesis becomes a *theory*.
- A theory is a hypothesis that
  - explains earlier observations
  - predicts further observations
- In our context, a theory is called a *diagnosis*
  (Contrast to popular usage, where a theory is a vague guess)

Mastermind

- A Mastermind game is a typical example of applying the scientific method.
- Create hypotheses until the theory predicts the secret.

Scientific Method of Debugging



A Sample Program

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

$ sample 11 14
Output: 0 11
```

Let’s use the scientific method to debug this.

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Initial Hypothesis

Hypothesis	“sample 11 14” works.
Prediction	Output is “11 14”
Experiment	Run sample as above.
Observation	Output is “0 11”
Conclusion	Hypothesis is **rejected**.

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```
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;
}
```

Does a[0] = 0 hold?

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Hypothesis 1: a[]

Hypothesis	The execution causes a[0] = 0
Prediction	At Line 37, a[0] = 0 should hold.
Experiment	Observe a[0] at Line 37.
Observation	a[0] = 0 holds as predicted.
Conclusion	Hypothesis is **confirmed**.


```
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);
}
```

Is the state sane here?

Hypothesis 2: shell_sort()

Hypothesis	The infection does not take place until shell_sort.
Prediction	At Line 6, a[] = [11, 14]; size = 2
Experiment	Observe a[] and size at Line 6.
Observation	a[] = [11, 14, 0]; size = **3**.
Conclusion	Hypothesis is **rejected**.

Hypothesis 3: size

Hypothesis	size = 3 causes the failure.
Prediction	Changing size to 2 should make the output correct.
Experiment	Set size = 2 using a debugger.
Observation	As predicted.
Conclusion	Hypothesis is **confirmed**.

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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
```

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Hypothesis 4: argc

Hypothesis	Invocation of shell_sort with size = argc causes the failure.
Prediction	Changing argc to argc - 1 should make the run successful.
Experiment	Change argc to argc - 1 and recompile.
Observation	As predicted.
Conclusion	Hypothesis is **confirmed**.

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The Diagnosis

- Cause is "Invoking shell_sort() with argc"
- Proven by two experiments:
  - Invoked with argc, the failure occurs;
  - Invoked with argc – 1, it does not.
- Side-effect: we have a *fix*
  (Note that we don't have *correctness* – but take my word)

Explicit Debugging

- Being *explicit* is important to understand the problem.
- Just *stating* the problem can already solve it.

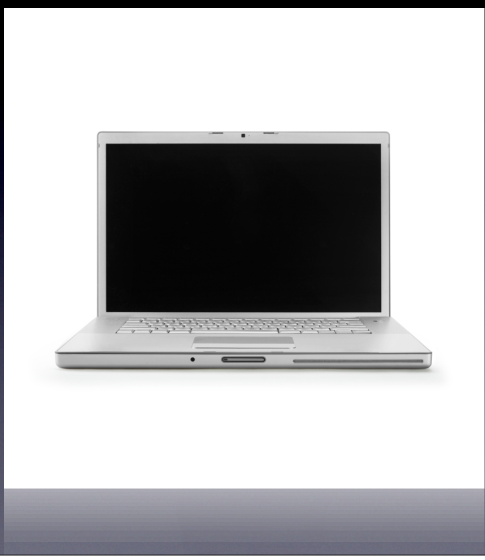
http://www.varsityclub.harvard.edu/Logos/teddy.gif

Keeping Track

- In a Mastermind game, *all* hypotheses and observations are explicit.
- Makes playing the game much easier.

Implicit Debugging

- Remember your last debugging session: Did you write down hypotheses and observations?
- Not being explicit forces you to keep all hypotheses and outcomes *in memory*
- Like playing Mastermind in memory



Keep a Notebook

Everything gets written down, formally, so that you know at all times

- where you are,
- where you've been,
- where you're going, and
- where you want to get.

Otherwise the problems get so complex you get lost in them.

What to Keep

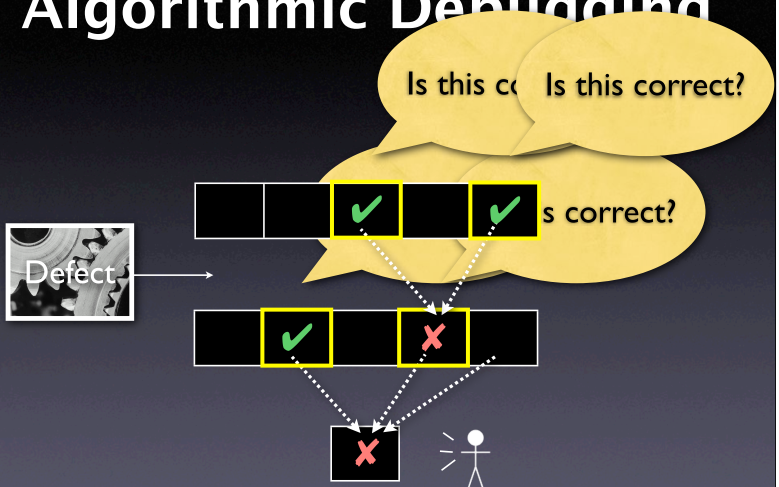
Faced with a difficult task,
"sleeping on it" makes students
three times more apt
to solve the task the next morning.


```
@Article{wagner/etal/2004/nature,
  author = {Ullrich Wagner and Steffen Gais and Hilde Haider and Rolf Verleger and Jan Born},
  title = {Sleep inspires insight},
  journal = {Nature},
  year = 2004,
  volume = 427
```


Quick and Dirty

- Not every problem needs the strength of the scientific method or a notebook – a quick-and-dirty process suffices.
- Suggestion: Go quick and dirty for 10 minutes, and then apply the scientific method.

Algorithmic Debugging



Algorithmic Debugging

1. Assume an incorrect result R with origins $O_1, O_2, \ldots, O_n$
2. For each O_i, enquire whether O_i is correct
3. If some O_i is incorrect, continue at Step 1
4. Otherwise (all O_i are correct), we found the defect

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```
def insert(elem, list):
    if len(list) == 0:
        return [elem]
    head = list[0]
    tail = list[1:]
    if elem <= head:
        return list + [elem]
    return [head] + insert(elem, tail)


def sort(list):
    if len(list) <= 1:
        return list
    head = list[0]
    tail = list[1:]
    return insert(head, sort(tail))
```

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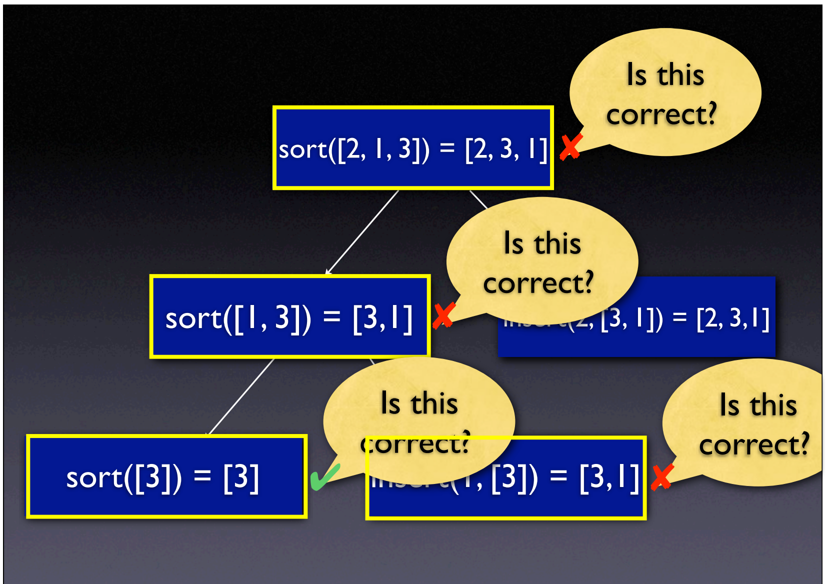

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Defect Location

- insert() produces an incorrect result and has no further origins:
- It must be the source of the incorrect value

insert(1, [3]) = [3,1] ✘

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```
def insert(elem, list):
    if len(list) == 0:
        return [elem]
    head = list[0]
    tail = list[1:]
    if elem <= head:                [elem] + list
        return list + [elem]
    return [head] + insert(elem, tail)


def sort(list):
    if len(list) <= 1:
        return list
    head = list[0]
    tail = list[1:]
    return insert(head, sort(tail))
```


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Discussion

- ✔ Detects defects systematically
- ✔ Works naturally for logical + functional computations
- ✘ Won't work for large states (and imperative computations)
- ✘ Do programmers like being driven?

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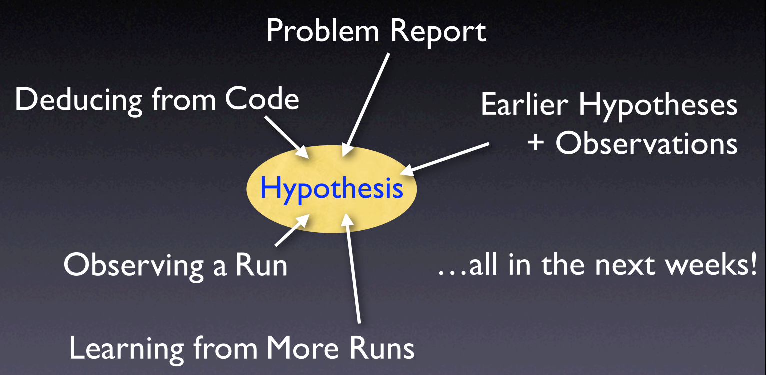
Oracles

- In algorithmic debugging, the user acts as an *oracle* – telling correct from false results
- With an *automatic oracle* could isolate any defect automatically.
- How complex would such an oracle be?

Obtaining a Hypothesis



Sources of Hypotheses

Experimentation	*n* controlled runs
Induction	*n* runs
Observation	1 run
Deduction	0 runs

Concepts

- A *cause* of any event (”effect”) is a preceding event without which the effect would not have occurred.
- To isolate a failure cause, use the *scientific method.*
- Make the problem and its solution *explicit.*

Concepts

- Algorithmic debugging organizes the scientific method by having the user assess outcomes
- Best suited for functional and logical programs