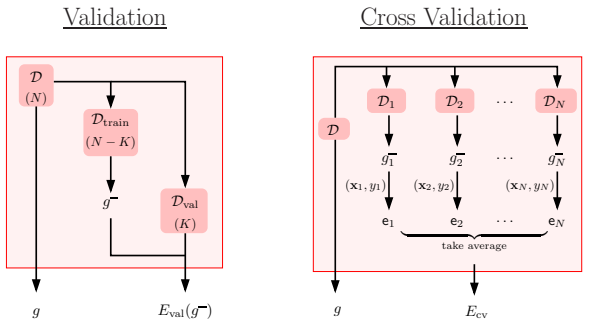
Learning From Data
Lecture 14
Three Learning Principles

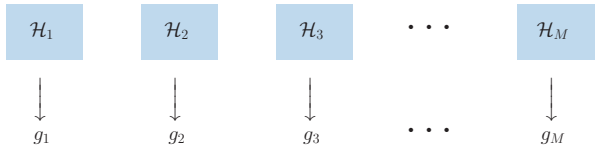
Occam's Razor
Sampling Bias
Data Snooping

M. Magdon-Ismail
CSCI 4100/6100

RECAP: ## Validation and Cross Validation



Model Selection



We Will Discuss . . .

- **Occam's Razor**: pick a model carefully
- **Sampling Bias**: generate the data carefuly
- **Data Snooping**: handle the data carefully

Occam's Razor

Occam's Razor

use a '**razor**' to 'trim down'

"an explanation of the data to make it as simple as possible but no simpler."

attributed to William of Occam (14th Century) and often mistakenly to Einstein

Simpler is Better

The simplest model that fits the data is also the most plausible.

. . . or, beware of using complex models to fit data

What is Simpler?

simple hypothesis h

$\Omega(h)$

low order polynomial
hypothesis with small weights
easily described hypothesis
⋮

What is Simpler?

simple hypothesis h

$\Omega(h)$

low order polynomial
hypothesis with small weights
easily described hypothesis
⋮

simple hypothesis set $\mathcal{H}$

$\Omega(\mathcal{H})$

$\mathcal{H}$ with small d_{vc}
small number of hypotheses
low entropy set
⋮

What is Simpler?

simple hypothesis h	simple hypothesis set $\mathcal{H}$
$\Omega(h)$	$\Omega(\mathcal{H})$
low order polynomial	$\mathcal{H}$ with small d_{VC}
hypothesis with small weights	small number of hypotheses
easily described hypothesis	low entropy set
⋮	⋮

The equivalence:

A hypothesis set with **simple** hypotheses *must be* **small**

We had a glimpse of this:

soft order constraint (smaller $\mathcal{H}$) $\xleftarrow{\lambda}$ minimize E_{aug} (favors simpler h).

Why is Simpler Better

Mathematically: simple curtails ability to fit noise, VC-dimension is small, and blah and blah ...

simpler is better because you will be more "surprised" when you fit the data.

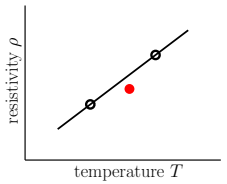
If something unlikely happens, it is very significant when it happens.

⋮
Detective Gregory: "Is there any other point to which you would wish to draw my attention?"
Sherlock Holmes: "To the curious incident of the dog in the night-time."
Detective Gregory: "The dog did nothing in the night-time."
Sherlock Holmes: "That was the curious incident."
⋮

– *Silver Blaze*, Sir Arthur Conan Doyle

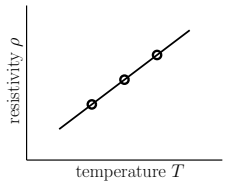
A Scientific Experiment

Scientist 3

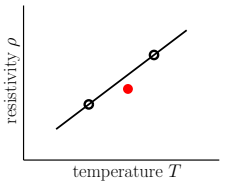


A Scientific Experiment

Scientist 2

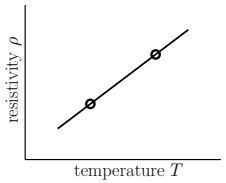


Scientist 3

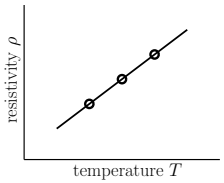


A Scientific Experiment

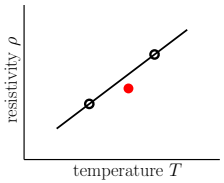
Scientist 1



Scientist 2

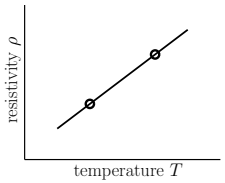


Scientist 3

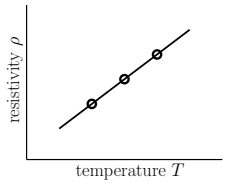


A Scientific Experiment

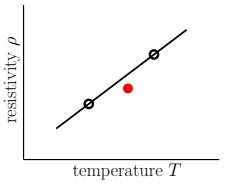
Scientist 1



Scientist 2



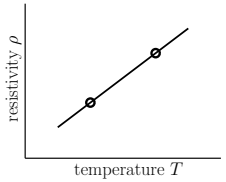
Scientist 3



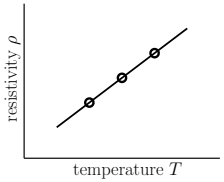
Who provides most evidence for the hypothesis "ρ is linear in T"?

Scientist 2 Versus Scientist 3

Scientist 1

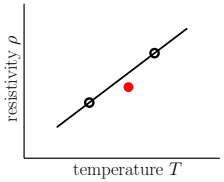


Scientist 2



very convincing

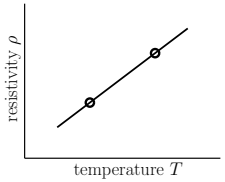
Scientist 3



some evidence?

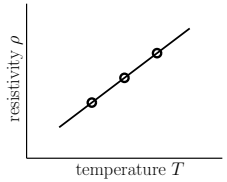
Scientist 1 versus Scientist 3

Scientist 1

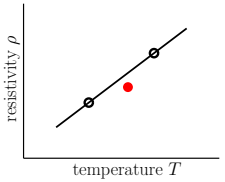


no evidence

Scientist 2



Scientist 3

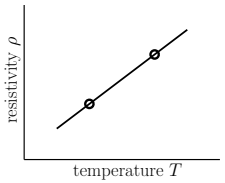


some evidence?

Axiom of Non-Falsifiability

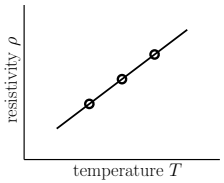
Axiom. If an experiment has no chance of falsifying a hypothesis, then the result of that experiment provides no evidence one way or the other for the hypothesis.

Scientist 1



no evidence

Scientist 2



very convincing

Falsification and $m_{\mathcal{H}}(N)$

If $\mathcal{H}$ shatters $\mathbf{x}_1, \cdots, \mathbf{x}_N$,

– Don't be surprised if you fit the data.

– Can't falsify "$\mathcal{H}$ is a good set of candidate hypotheses for f".

Falsification and $m_{\mathcal{H}}(N)$

If $\mathcal{H}$ shatters $\mathbf{x}_1, \cdots, \mathbf{x}_N$,

– Don't be surprised if you fit the data.

– Can't falsify "$\mathcal{H}$ is a good set of candidate hypotheses for f".

If $\mathcal{H}$ doesn't shatter $\mathbf{x}_1, \cdots, \mathbf{x}_N$, and the target values are uniformly distributed,

$$\mathbb{P}[\text{falsification}] \geq 1 - \frac{m_{\mathcal{H}}(N)}{2^N}\,.$$

A good fit is surprising with simple $\mathcal{H}$, hence significant. You can, but didn't falsify "$\mathcal{H}$ is a good set of candidate hypotheses for f"

Falsification and $m_{\mathcal{H}}(N)$

If $\mathcal{H}$ shatters $\mathbf{x}_1, \cdots, \mathbf{x}_N$,

– Don't be surprised if you fit the data.

– Can't falsify "$\mathcal{H}$ is a good set of candidate hypotheses for f".

If $\mathcal{H}$ doesn't shatter $\mathbf{x}_1, \cdots, \mathbf{x}_N$, and the target values are uniformly distributed,

$$\mathbb{P}[\text{falsification}] \geq 1 - \frac{m_{\mathcal{H}}(N)}{2^N}\,.$$

A good fit is surprising with simple $\mathcal{H}$, hence significant. You can, but didn't falsify "$\mathcal{H}$ is a good set of candidate hypotheses for f"

The data *must* have a *chance* to win.

Learning Goes Beyond Occam's Razor

We may opt for 'a simpler fit than possible', namely an imperfect fit of the data using a simple model over a perfect fit using a more complex one. The reason is that the price we pay for a perfect fit in terms of the penalty for model complexity may be too much in comparison to the benefit of the better fit.

– *Learning From Data*, Abu-Mostafa, Magdon-Ismail, Lin

Postal Scam

A Puzzle – The Football Oracle

Saturday, Oct 13, 2012

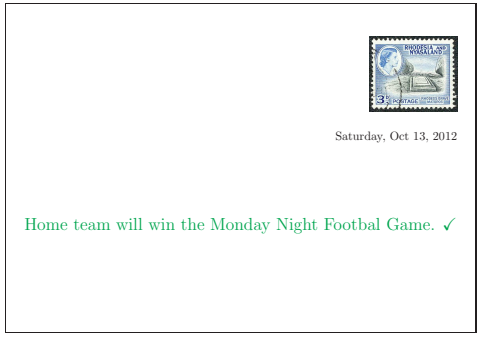
Home team will win the Monday Night Footbal Game.

A Puzzle – The Football Oracle

Saturday, Oct 13, 2012

Home team will win the Monday Night Footbal Game. ✓

A Puzzle – The Football Oracle



Saturday, Oct 13, 2012

Home team will win the Monday Night Footbal Game. ✓

This happens for 5 weeks in a row.

A Puzzle – The Football Oracle . . . on the 6th week

Saturday, Nov 17, 2012

Call 1-900-555-5555 for winner; **$50** charge applied

$E_{\text{in}} = 0!$

What did the Oracle Really Do?

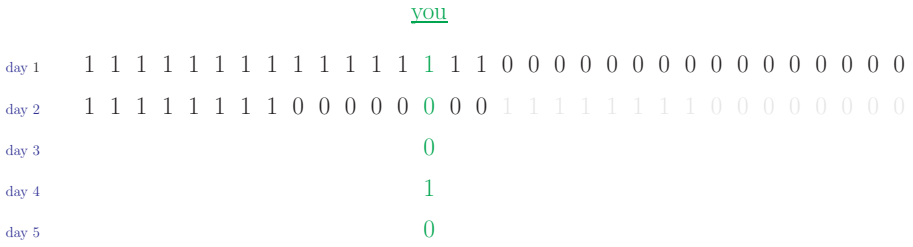
	you
day 1	1
day 2	0
day 3	0
day 4	1
day 5	0

Single hypothesis that worked?

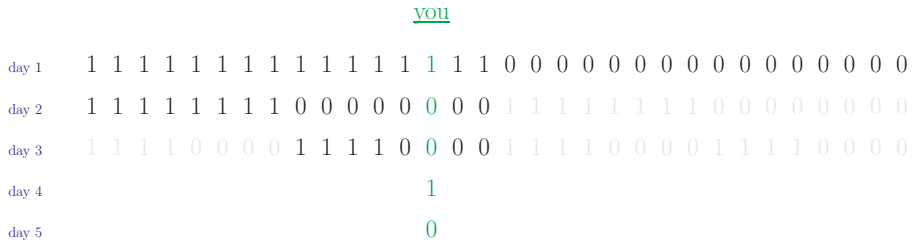
What did the Oracle Really Do?

	you
day 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
day 2	0
day 3	0
day 4	1
day 5	0

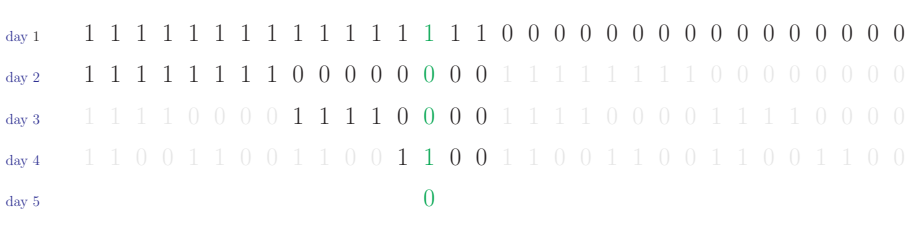
What did the Oracle Really Do?



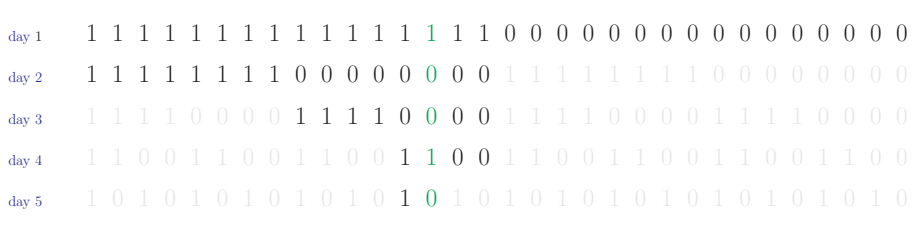
What did the Oracle Really Do?



What did the Oracle Really Do?



What did the Oracle Really Do?



What did the Oracle Really Do?

you

day 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
day 2	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
day 3	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0
day 4	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
day 5	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Every possible hypothesis one of which worked?

A Puzzle – The Football Oracle . . . on the 6th week

Saturday, Nov 17, 2012

Call 1-900-555-5555 for winner; **$50** charge applied

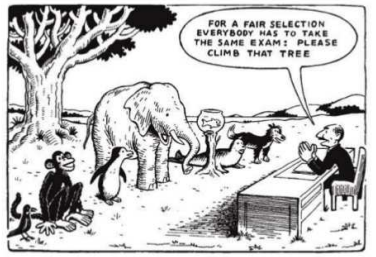
$E_{\text{in}} = 0$!

Meaningless without the 'complexity' of the process leading to that!

We Will Discuss . . .

- **Occam's Razor**: pick a model carefully ✓
- **Sampling Bias**: generate the data carefuly
- **Data Snooping**: handle the data carefully

Sampling Bias



November 3rd 1948, Dewey Defeats Truman

Tribune wanted to show off its latest technology
could go earlier to press.

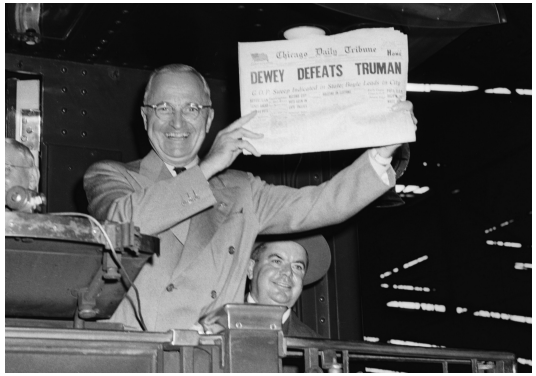
Telephone poll on how people voted
statisticians had done their thing and were confident.


Chicago Daily Tribune

DEWEY DEFEATS TRUMAN

G.O.P. Sweep Indicated in State; Boyle Leads in City

Imagine Their Surprise When . . .



Sampling Bias in Learning

If the data is sampled in a biased way, learning will produce a similarly biased outcome.

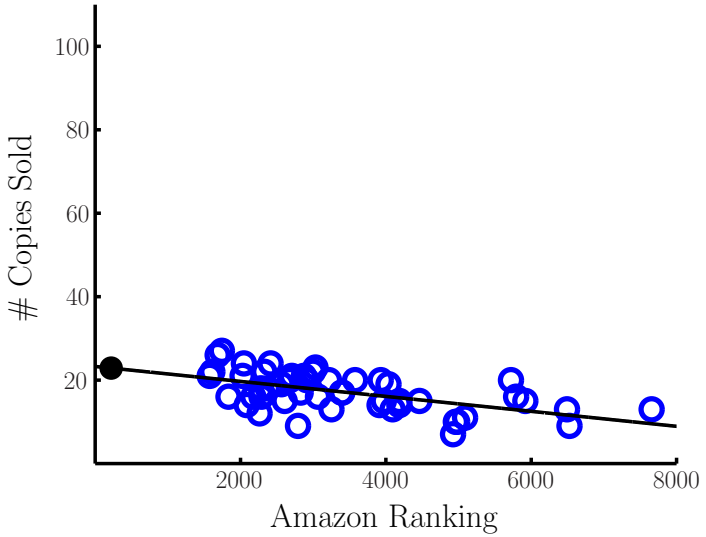
. . . or, make sure the training and test distributions are the same.

You cannot draw a sample from one bin and make claims about *another* bin

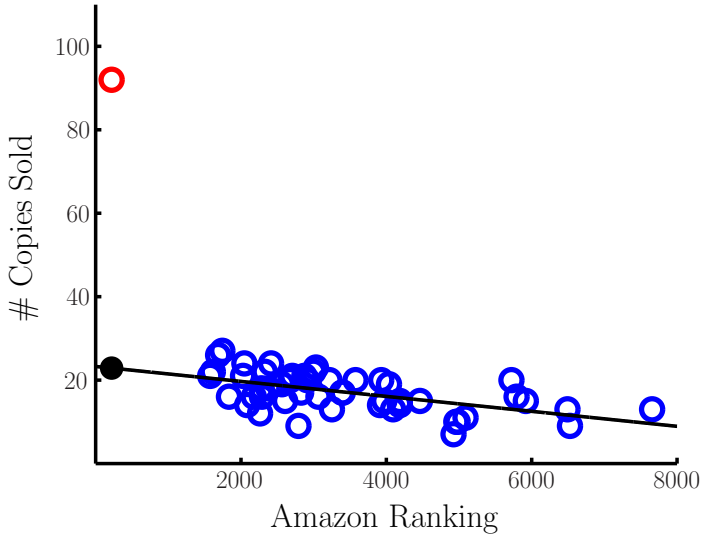
Examples

- Kids and social media – the highlight reel.
- Taller, Fatter, Older: How Humans Have Changed in 100 Years.
- The GRE: A test that fails.

Extrapolation



Extrapolation is Hard

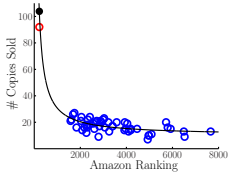


Dealing with the Training-Test Mismatch

Think more carefully about what f should look like

Need some additional help outside the data, by choosing a good $\mathcal{H}$

In our ranking example, account for the fat tail ⟶ hyperbola



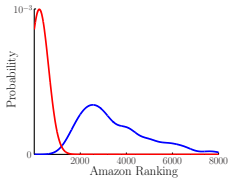
(hyperbola fit)

Account for the training-test mismatch during learning

There are methods that reweight/resample data can help

If test data have zero representation in training, you are in trouble

— Think carefully about f ☺



(test versus training distributions)

Puzzle - Credit Analysis

- Determine credit given salary, debt, years in residence, ...
- Banks have lots of data
  - customer information: salary, debt, etc.
  - whether or not they defaulted on their credit.

age	32 years
gender	male
salary	40,000
debt	26,000
years in job	1 year
years at home	3 years
...	...

Approve for credit?

where is the sampling bias?

Puzzle - Credit Analysis

- Determine credit given salary, debt, years in residence, ...
- Banks have lots of data
  - customer information: salary, debt, etc.
  - whether or not **who?** defaulted on their credit.

age	32 years
gender	male
salary	40,000
debt	26,000
years in job	1 year
years at home	3 years
...	...

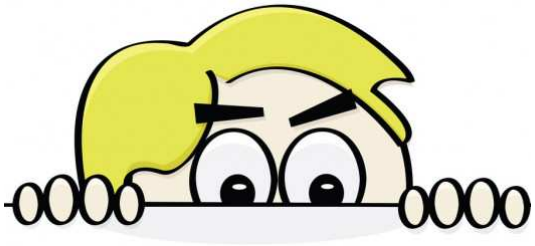
Approve for credit?

only data on approved customers

We Will Discuss ...

- **Occam's Razor**: pick a model carefully ✓
- **Sampling Bias**: generate the data carefuly ✓
- **Data Snooping**: handle the data carefully

Data Snooping



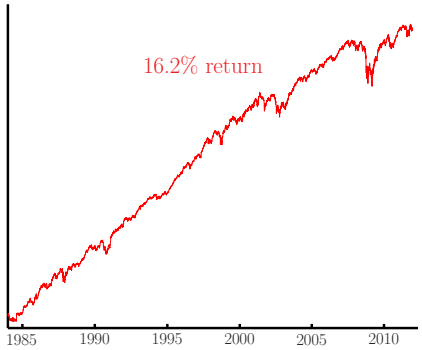
Data Snooping

If a data set has affected any step in the learning process, it cannot be fully trusted in assessing the outcome.

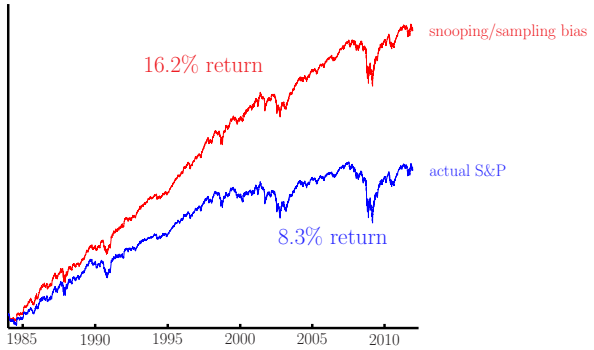
... or, estimate performance with a *completely* uncontaminated test set

... and, choose $\mathcal{H}$ **before** looking at the data

Puzzle: The Buy and Hold Strategy on S&P 500 Stocks



Puzzle: The Buy and Hold Strategy on S&P 500 Stocks



Sampling Bias: didn't buy and hold a random sample of stocks.

Snooping: *Choose* which stocks to hold by 'snooping' into the test set (the future).

Data Snooping is a Subtle Happy Hell

- The data looks linear, so I will use a linear model, and it worked.
  If the data were different and didn't look linear, would you do something different?

Data Snooping is a Subtle Happy Hell

- The data looks linear, so I will use a linear model, and it worked.
  If the data were different and didn't look linear, would you do something different?
- Try linear, it fails; try circles it works.
  If you torture the data enough, it will confess.
- Try linear, it works; so I don't need to try circles.
  Would you have tried circles if the data were different?

Data Snooping is a Subtle Happy Hell

- The data looks linear, so I will use a linear model, and it worked.
  If the data were different and didn't look linear, would you do something different?
- Try linear, it fails; try circles it works.
  If you torture the data enough, it will confess.
- Try linear, it works; so I don't need to try circles.
  Would you have tried circles if the data were different?
- Read papers, see what others did on the data. Modify and improve on that.
  If the data were different, would that modify what others did and hence what you did?
  the data snooping can happen all at once or sequentially by different people

Data Snooping is a Subtle Happy Hell

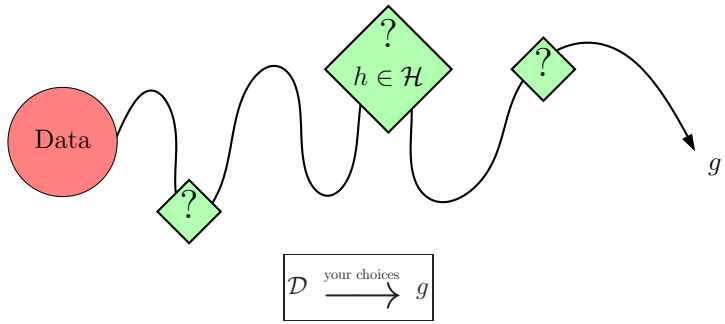
- The data looks linear, so I will use a linear model, and it worked.
  If the data were different and didn't look linear, would you do something different?
- Try linear, it fails; try circles it works.
  If you torture the data enough, it will confess.
- Try linear, it works; so I don't need to try circles.
  Would you have tried circles if the data were different?
- Read papers, see what others did on the data. Modify and improve on that.
  If the data were different, would that modify what others did and hence what you did?
  the data snooping can happen all at once or sequentially by different people
- Input normalization: normalize the data, now set aside the test set.
  Since the test set was involved in the normalization, wouldn't your g change if the test set changed?

Account for Data Snooping

Ask yourself: "If the *data* were different, could/would I have done something different?"
if yes, then there is data snooping.

Account for Data Snooping

Ask yourself: "If the *data* were different, could/would I have done something different?"
if yes, then there is data snooping.



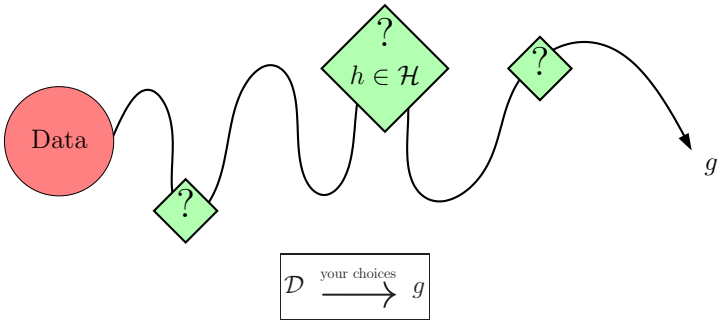
You must account for every choice influenced by $\mathcal{D}$.

We know how to account for the choice of g from $\mathcal{H}$.

Account for Data Snooping

Ask yourself: "If the *data* were different, could/would I have done something different?"

if yes, then there is data snooping.



You must account for ***every choice*** influenced by $\mathcal{D}$.

We know how to account for the choice of g from $\mathcal{H}$.

Three Learning Principles

- **Occam's Razor**: pick a model carefully ✓
  Simpler $\mathcal{H}$ is better.

- **Sampling Bias**: generate the data carefuly ✓
  Make sure you train and test from the same bin.

- **Data Snooping**: handle the data carefully ✓
  Account for all choices the data influenced. Choose $\mathcal{H}$ *before* you see the data.