Comparing models

Topics in Cognitive Modelling

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How do can we compare models?

What makes one model or theory better than another?

- Explanatory completeness
- Predictive accuracy
- Being understandable

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Explanatory completeness

Generality

A good model accurately explains many results

- Fits data from many experiments
- Captures qualitatively different phenomena

Precision

A good model is precise

- Specific predictions, less wiggle room

Generality

E.g., for physical forces and particles:

Electricity

↓

Classical electromagnetism (+ magnetism)

↓

Quantum electrodynamics (+ quantum phenomena)

↓

Standard model (+ nuclear forces)

↓

"Theory of everything"

(gravity, dark matter, dark energy …)

Precision

Beware vagueness!

- "*Stuff happens*" is a hypothesis, but vague one.
- Better: "*X is related to Y.*"
- Better: "*As X increases, Y will decrease.*"
- Better: "*As X increases, Y will decrease according to the following function …*"

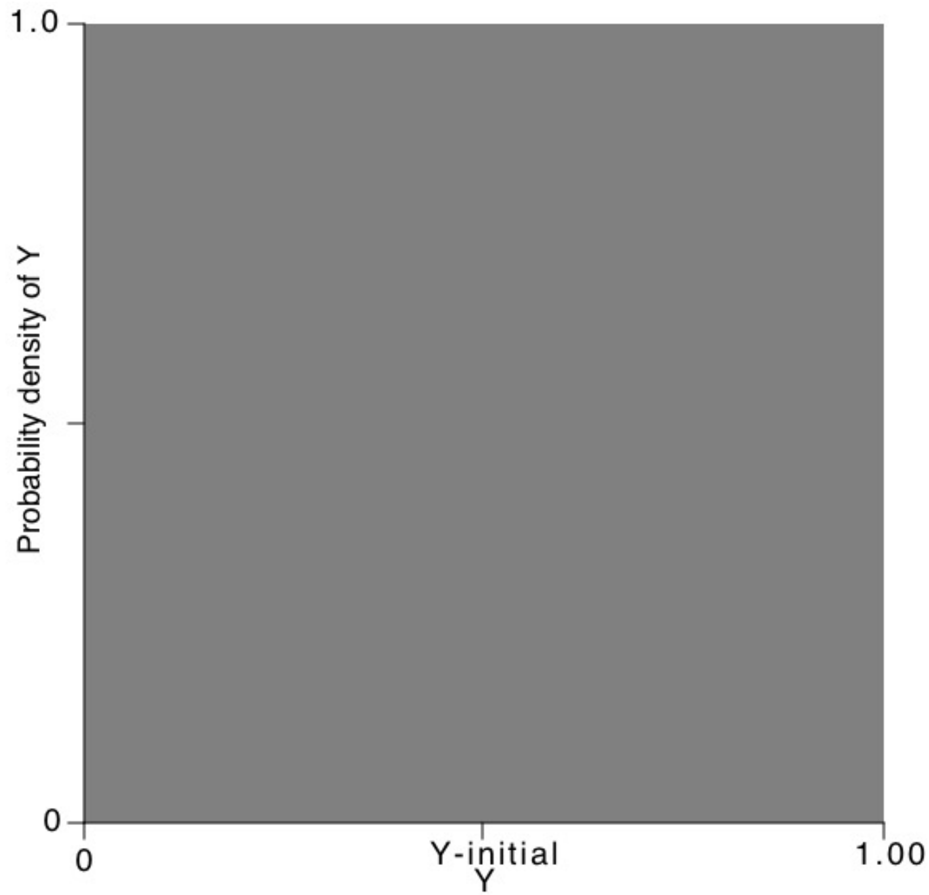
Probability theory lets us be precise about precision:

$$P(\mathbf{m}\text{odel}|\mathbf{d}\text{ata}) \propto P(m)P(d|m)$$

Precision

Suppose X increases. What do our different hypotheses say about Y?

"Stuff happens"



Precision

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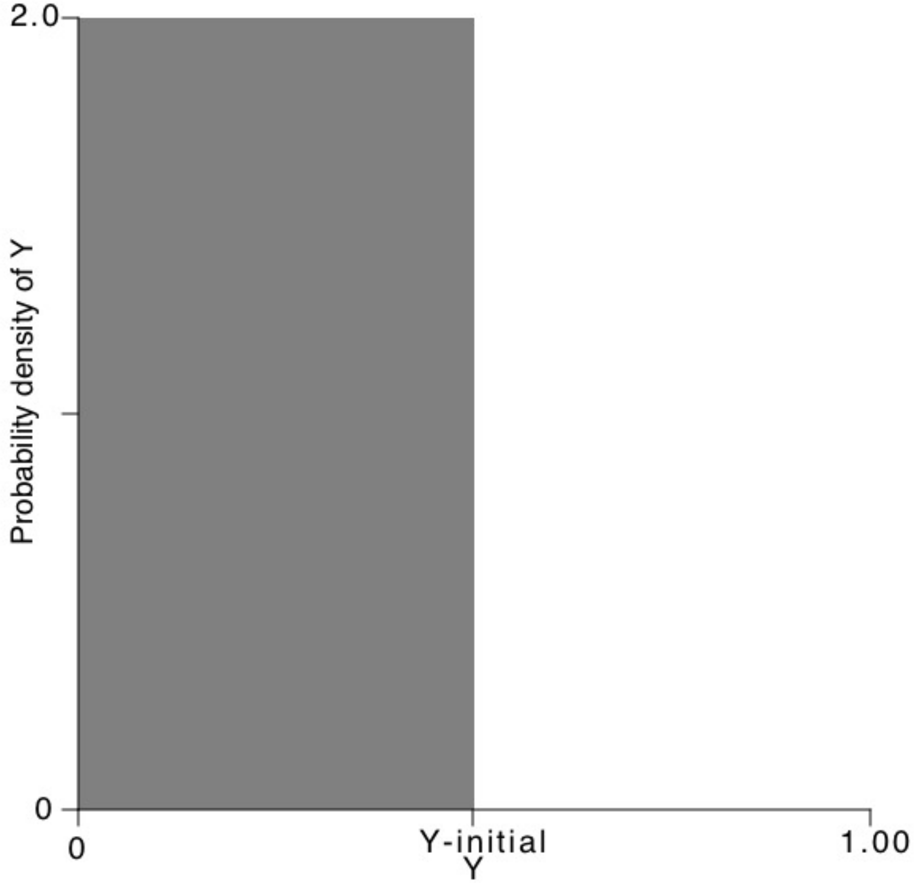

Precision

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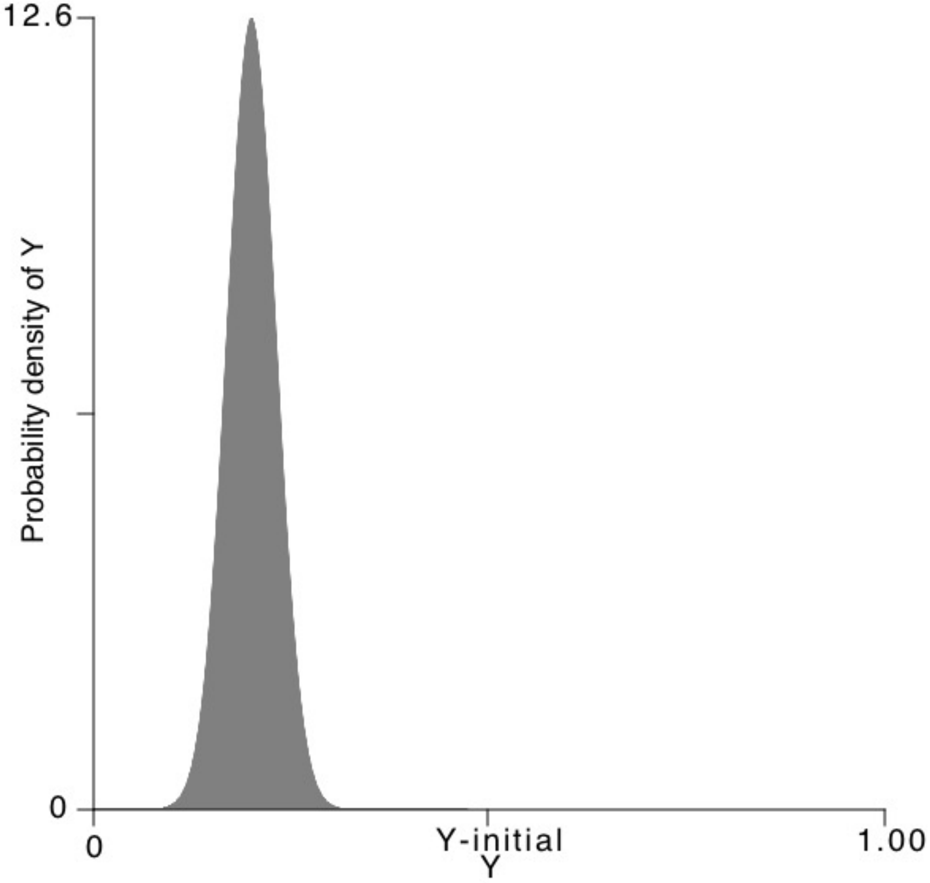
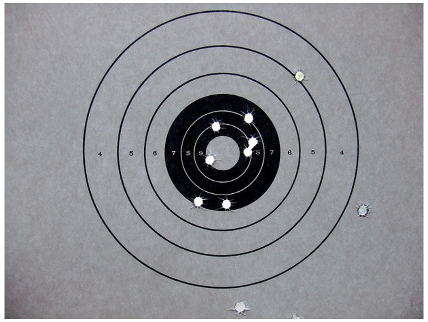


Explanatory completeness

Beware the limits of post-hoc explanations!

- The Texas sharpshooter fallacy
  - A.K.A., Don't just test on your training data



- "My model predicts where people shoot – you just need to specify the bullseye-location parameter for each person!"

Explanatory completeness

- We don’t want models that just explain data after the fact!
- Rather, we want models that do well on the enormous variety of cases we haven’t yet seen.

That is, predictive accuracy.

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Predictive accuracy

Straightforward in principle:

1. Make predictions
2. Collect data
3. Evaluate model
4. Publish results

Predictive accuracy

Difficult in practice:

1. Publication bias
2. |old data| >> |new data|
3. Choosing criteria/loss functions
4. Free parameters

Predictive accuracy

Can we estimate predictive accuracy using old data?

- Cross-validation
- “Information criteria”

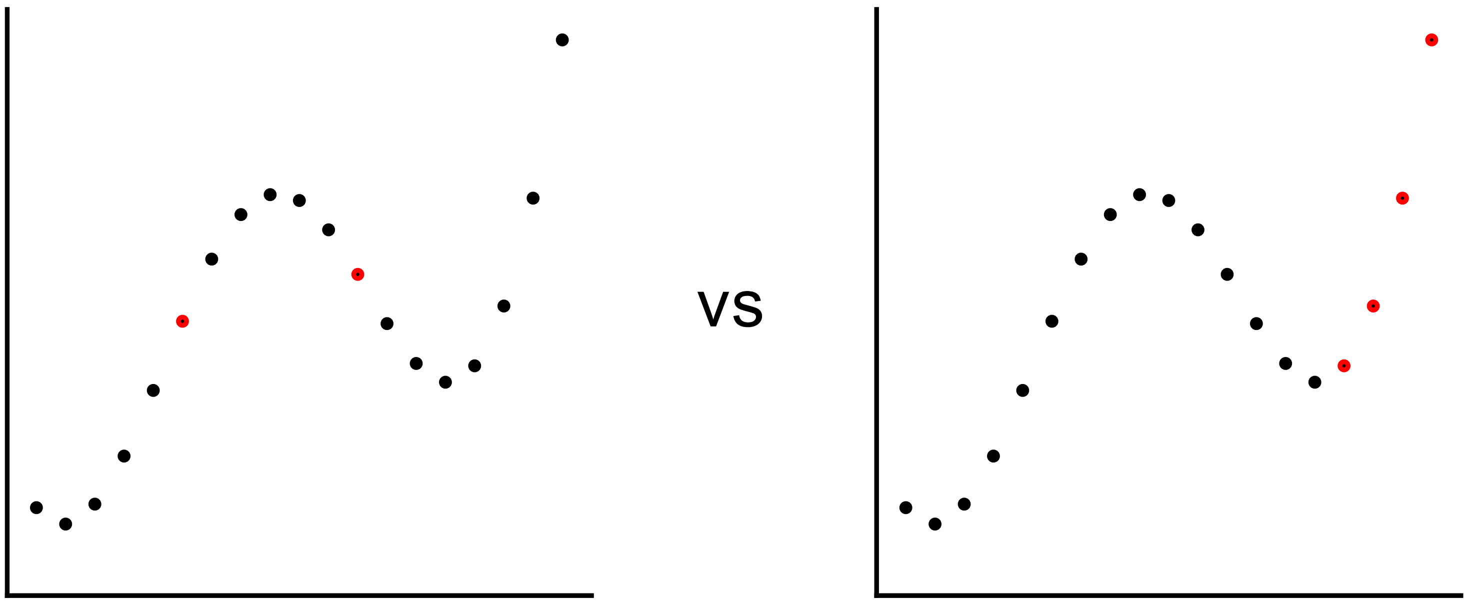
Cross-validation

1. Partition the data into training and validation sets
2. Fit the model on the training data
3. Get the probability* of the validation data under the fitted model.
4. Repeat steps for non-overlapping validation sets until all of the data have been covered.

Cross-validation

Issues:

- Can be computationally expensive
- Are cross-validation test sets like new cases?



Information criteria

Lower scores are better; generally

score = badness of fit + complexity penalty.

Most common badness of fit = -log(P(D|M,θ_{MLE}))

i.e., negative log likelihood of data given model, using likelihood-maximising parameters θ_{MLE}.

Perfect fit, e.g., P(D|M,θ_{MLE})=1 → badness of fit=0.

Information criteria

Different criteria vary by their complexity terms and goals:

Name	Goal	Fit term	Complexity term
Akaike **IC**	Find model with best hold-1-out cross validation accuracy[1,2]	$-2*\log(P(D\|M,\theta_{MLE}))$	2*k (k = # of params)
Bayesian **IC** (misnomer)	Find model with highest probability[1,2,3]	$-2*\log(P(D\|M,\theta_{MLE}))$	k*log(n) (n = # data points)
Watanabe-**A**kaike **IC**	Like AIC, but applies more generally	-log(P(D|M))[4]	Effective # params See (Wantanabe, 2010)

[1] Asymptotically

[2] If models are of a particular type (exponential family)

[3] If the true generating model is among those being tested

[4] Requires integrating over θ

(See also DIC, RIC)

Information criteria

Issues:

- Assumptions often aren't true
  - Sometimes a model is insensitive to a parameter or parameters are partially redundant
  - Sometimes a single parameter hides enormous flexibility
  - Sometimes parameters are hidden
- Criteria with weaker assumptions are sometimes intractable to compute (e.g., WAIC)

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Being understandable

- Part of a model's value is as a foundation for other models and theories.
- If we want to *understand* human cognition, then incomprehensible models aren't useful.
- One criterion: can a sophisticated person implement the model from a description?

Conclusions

Models are better when they're more

- General
- Precise
- Predictively accurate
- Parsimonious
- Comprehensible

Some of these notions can be expressed formally, e.g., using probability theory.

They should complement, rather than replace, your intuitions about how plausible, useful, or reasonable a model is.

References and further reading

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