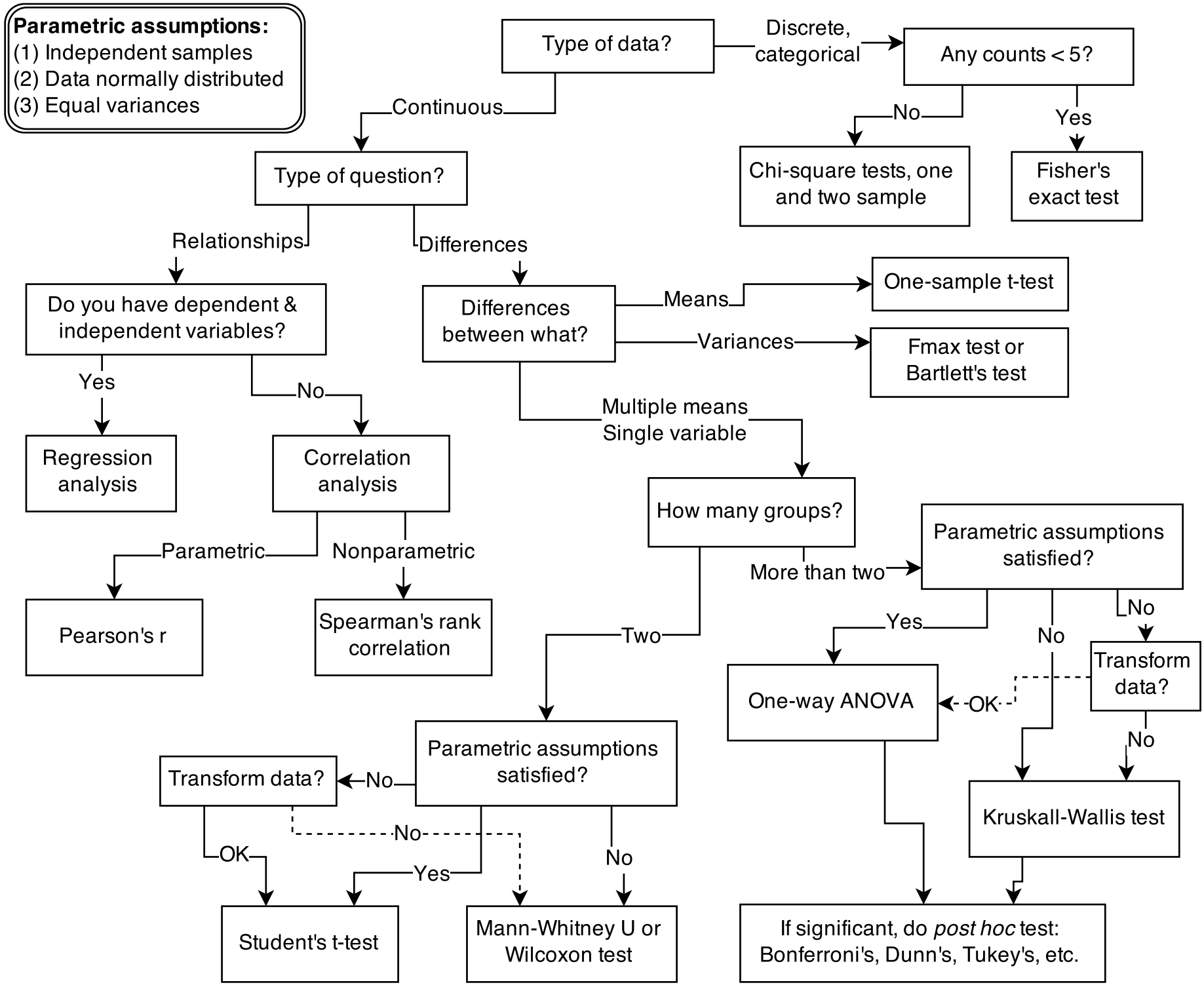
Statistical Rethinking
Winter 2019

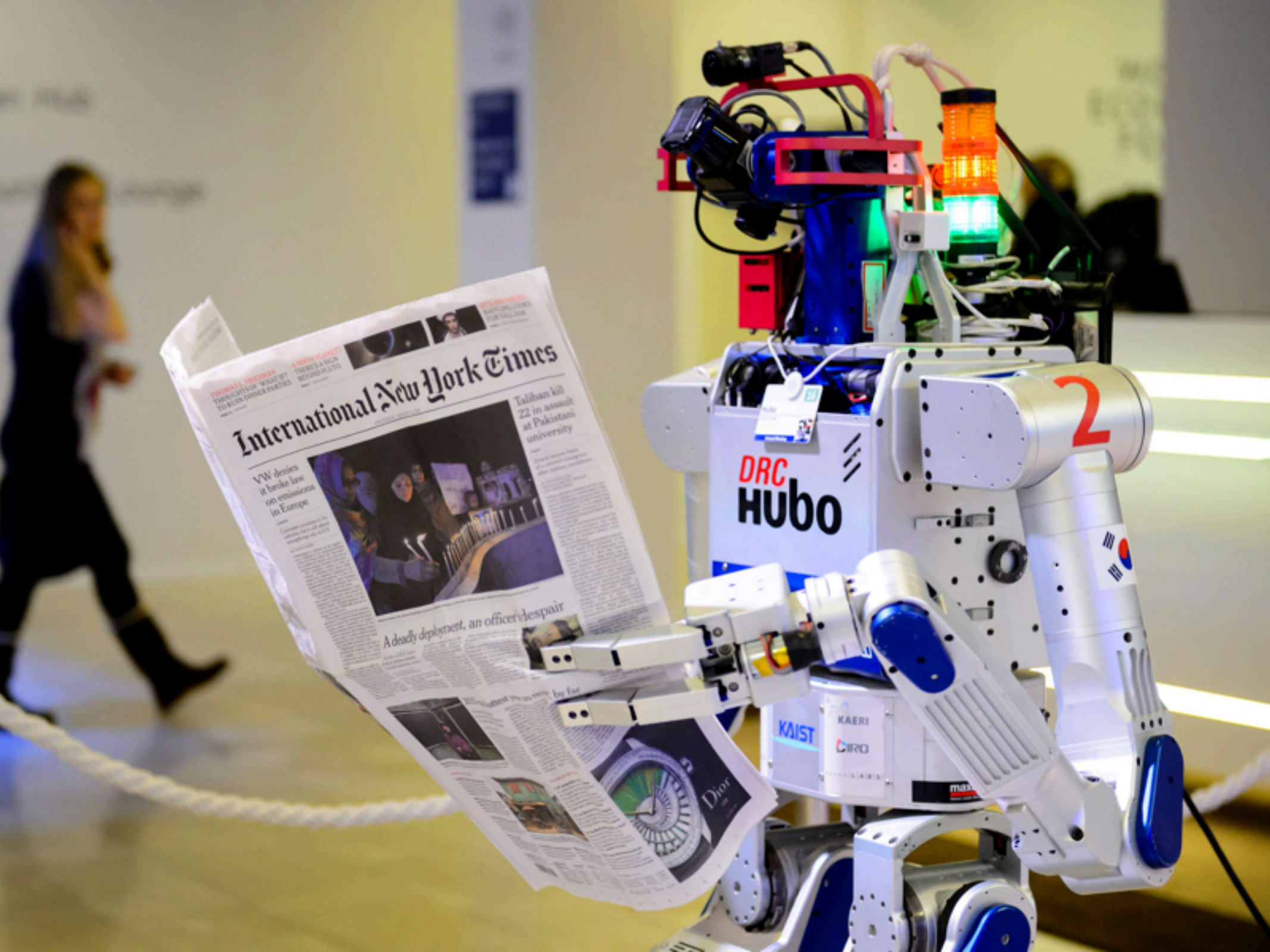
Week 1

The Golem of Prague

JJ Harrison, “*Phylidonyris novaehollandiae* Bruny Island”


R.A.FISHER
FELLOW 1920-26 1943-62
PRESIDENT 1956-59


Parametric assumptions:
(1) Independent samples
(2) Data normally distributed
(3) Equal variances
Type of data?
Discrete, categorical
Any counts < 5?
No
Yes
Chi-square tests, one and two sample
Fisher's exact test
Continuous
Type of question?
Relationships
Differences
Do you have dependent & independent variables?
Yes
No
Regression analysis
Correlation analysis
Parametric
Nonparametric
Pearson's r
Spearman's rank correlation
Differences between what?
Means
One-sample t-test
Variances
Fmax test or Bartlett's test
Multiple means Single variable
How many groups?
Two
More than two
Parametric assumptions satisfied?
Yes
No
No
Transform data?
OK
One-way ANOVA
No
Kruskall-Wallis test
Parametric assumptions satisfied?
Transform data?
No
OK
No
Yes
No
Student's t-test
Mann-Whitney U or Wilcoxon test
If significant, do post hoc test: Bonferroni's, Dunn's, Tukey's, etc.


International New York Times
DRC
HUBO
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KAIST
KAERI

The Golem of Prague

go•lem |gōləm|
noun
• (in Jewish legend) a clay figure brought to life by magic.
• an automaton or robot.

ORIGIN late 19th cent.: from Yiddish ***goylem***, from Hebrew ***gōlem***
'shapeless mass.'

The Golem of Prague

"Even the most perfect of Golem, risen to life to protect us, can easily change into a destructive force. Therefore let us treat carefully that which is strong, just as we bow kindly and patiently to that which is weak."

Rabbi Judah Loew ben Bezalel (1512–1609)

From *Breath of Bones: A Tale of the Golem*

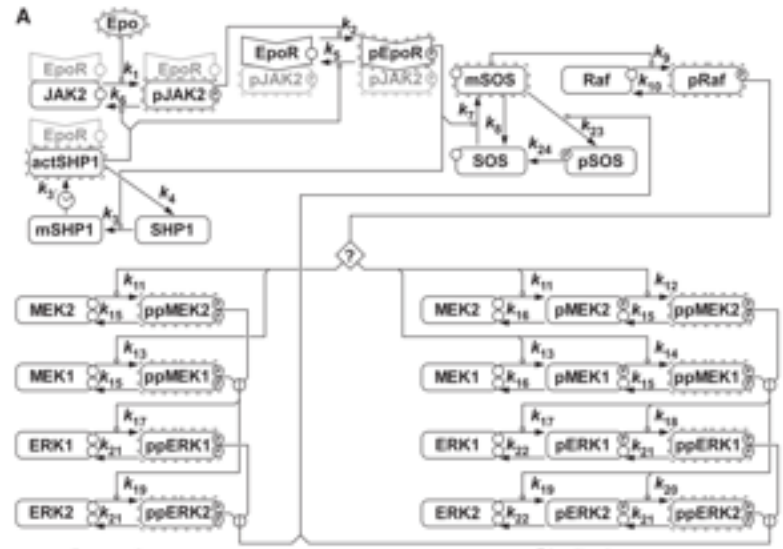
The Golems of Science

Golem

- Made of clay
- Animated by “truth”
- Powerful
- Blind to creator’s intent
- Easy to misuse
- Fictional

Model

- Made of...silicon?
- Animated by “truth”
- Hopefully powerful
- Blind to creator’s intent
- Easy to misuse
- Not even false



Statistical Rethinking
A Bayesian Course in R & Stan

Week 1	Bayesian inference	Chapters 1, 2, 3
Week 2	Linear models	Chapter 4
Week 3	More linear models	Chapters 5 & 6
Week 4	Overfitting	Chapter 7
Week 5	Interactions	Chapter 8
Week 6	MCMC & GLMs	Chapters 9, 10, 11
Week 7	GLMs II	Chapters 11 & 12
Week 8	Multilevel models I	Chapter 13
Week 9	Multilevel models II	Chapter 14
Week 10	Measurement error etc.	Chapters 15 & 16

https://github.com/rmcelreath/statrethinking_winter2019

Goals & Methods

- Practical model-building, model-criticizing skills
- Enough philosophy to ground you
- Enough confidence to be comfortable with confusion

Stan

http://mc-stan.org/

rethinking package (Experimental)

```
install.packages(c("coda","mvtnorm","devtools","loo"))
library(devtools)
devtools::install_github("rmcelreath/rethinking",
    ref="Experimental")
```

2nd Edition book draft

http://xcelab.net/rm/sr2/

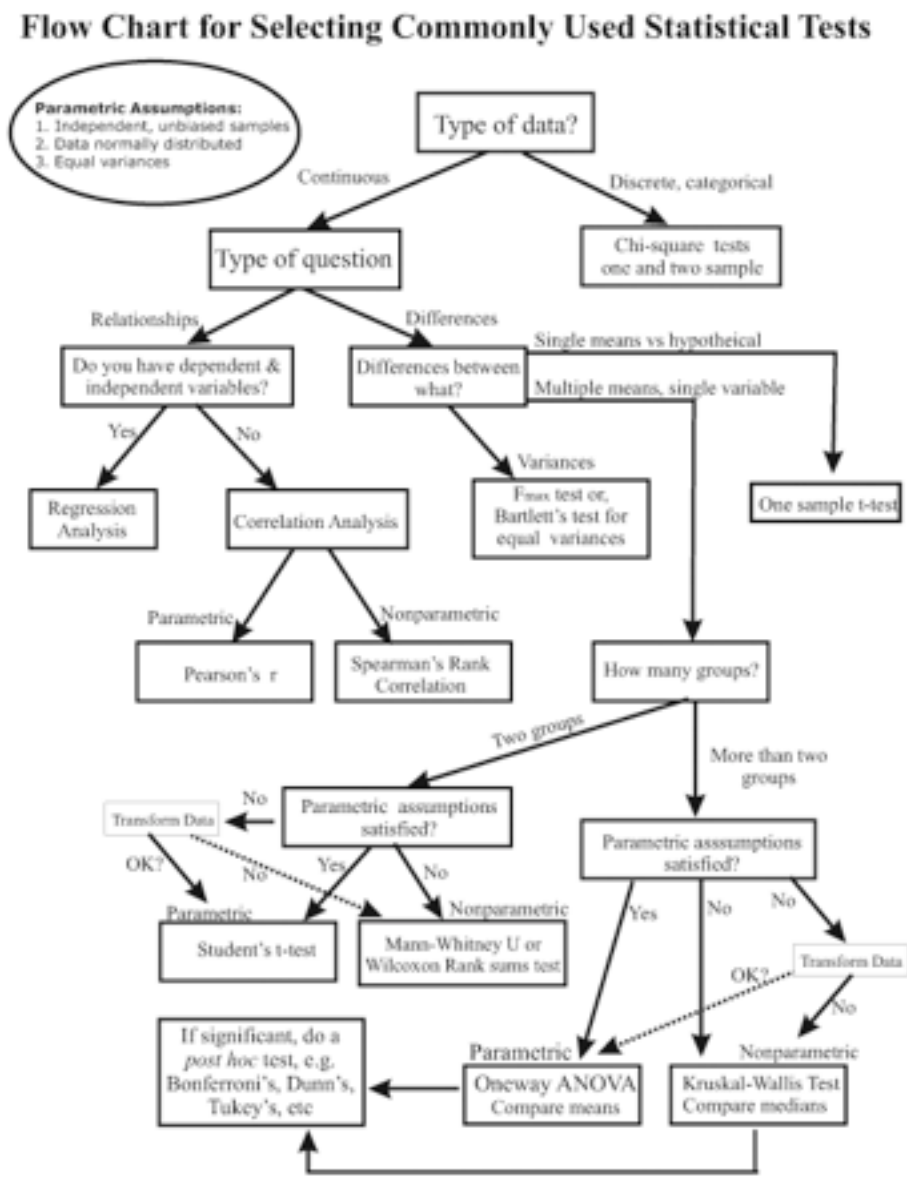
blossom

2nd Edition: Ch-Ch-Changes

- Lots of prior predictive simulation
- Causal inference: DAGs, colliders, instrumental variables
- `map` becomes `quap` (name change)
- `map2stan` replaced by `ulam`
- New examples

Against Tests

- Specialized, pre-made golems, “procedures”
- Most developed in early 20th century, fragile, eclipsed by more recent tools
- Users don’t know they are using models (golems)
- Falsifying *null* model not sufficient
- Inference is not decision



O, that way madness lies

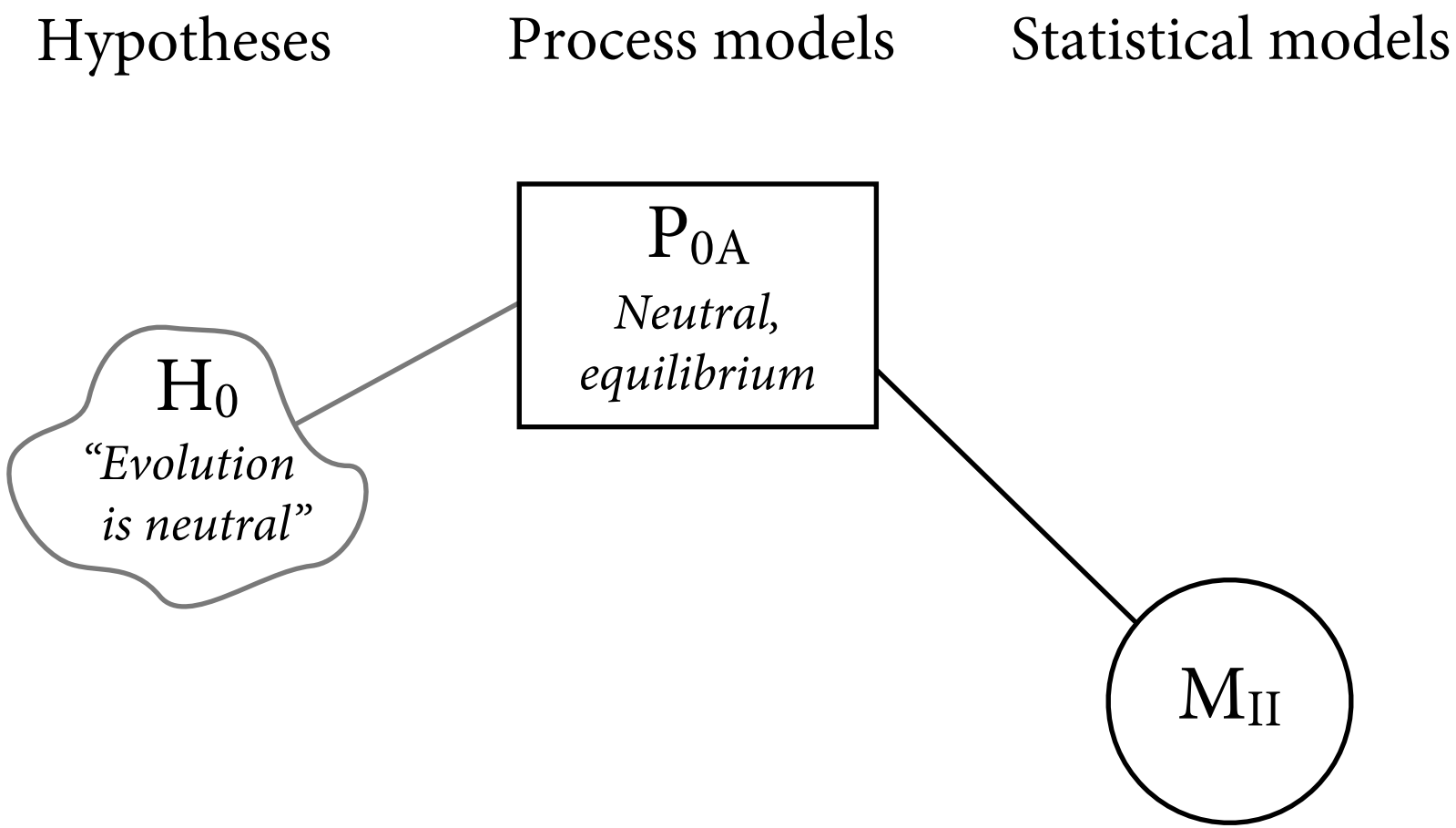

Hypotheses
Process models
Statistical models
P_{0A}
Neutral, equilibrium
H_0
"Evolution is neutral"
M_{II}

Figure 1.2

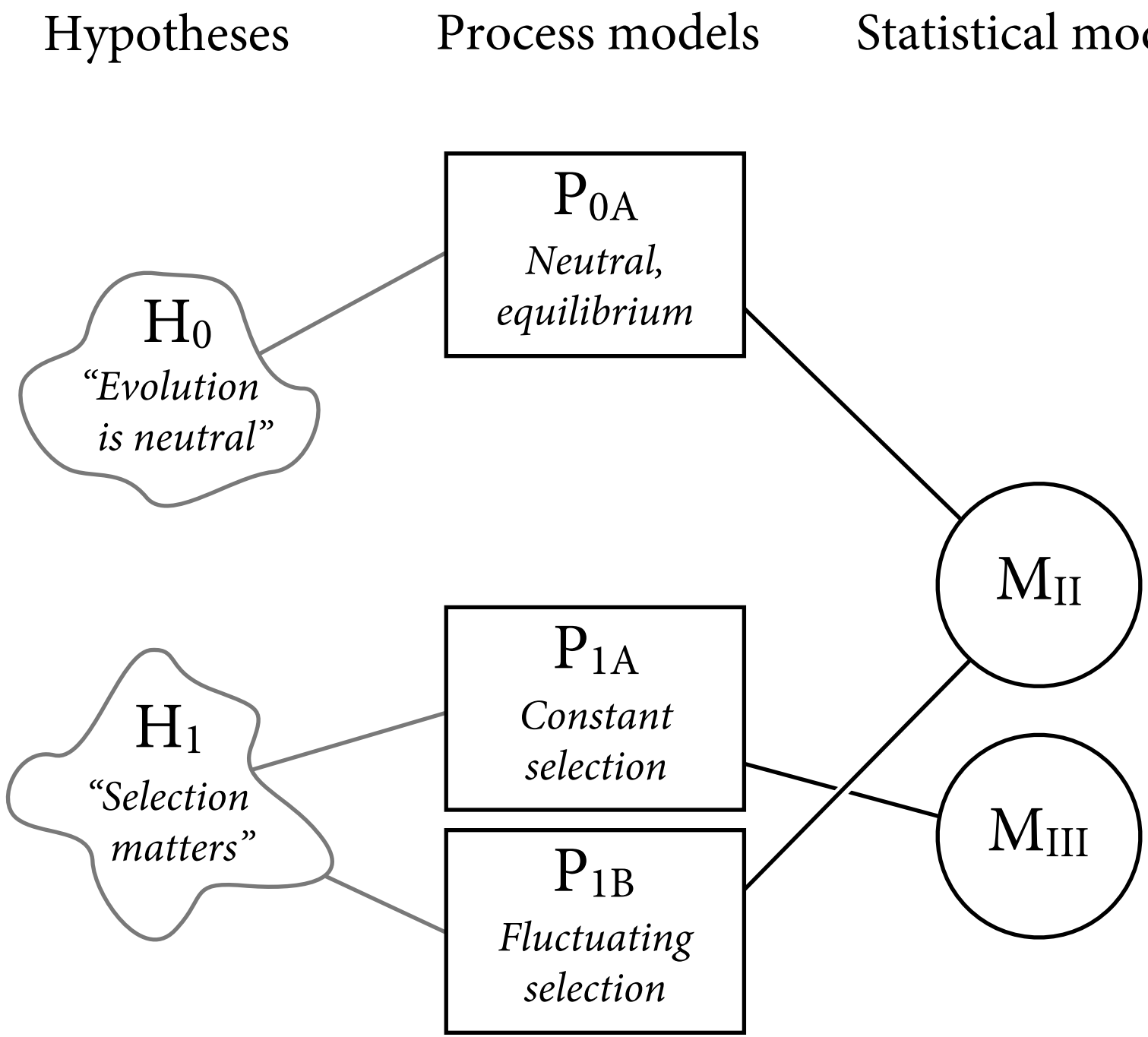
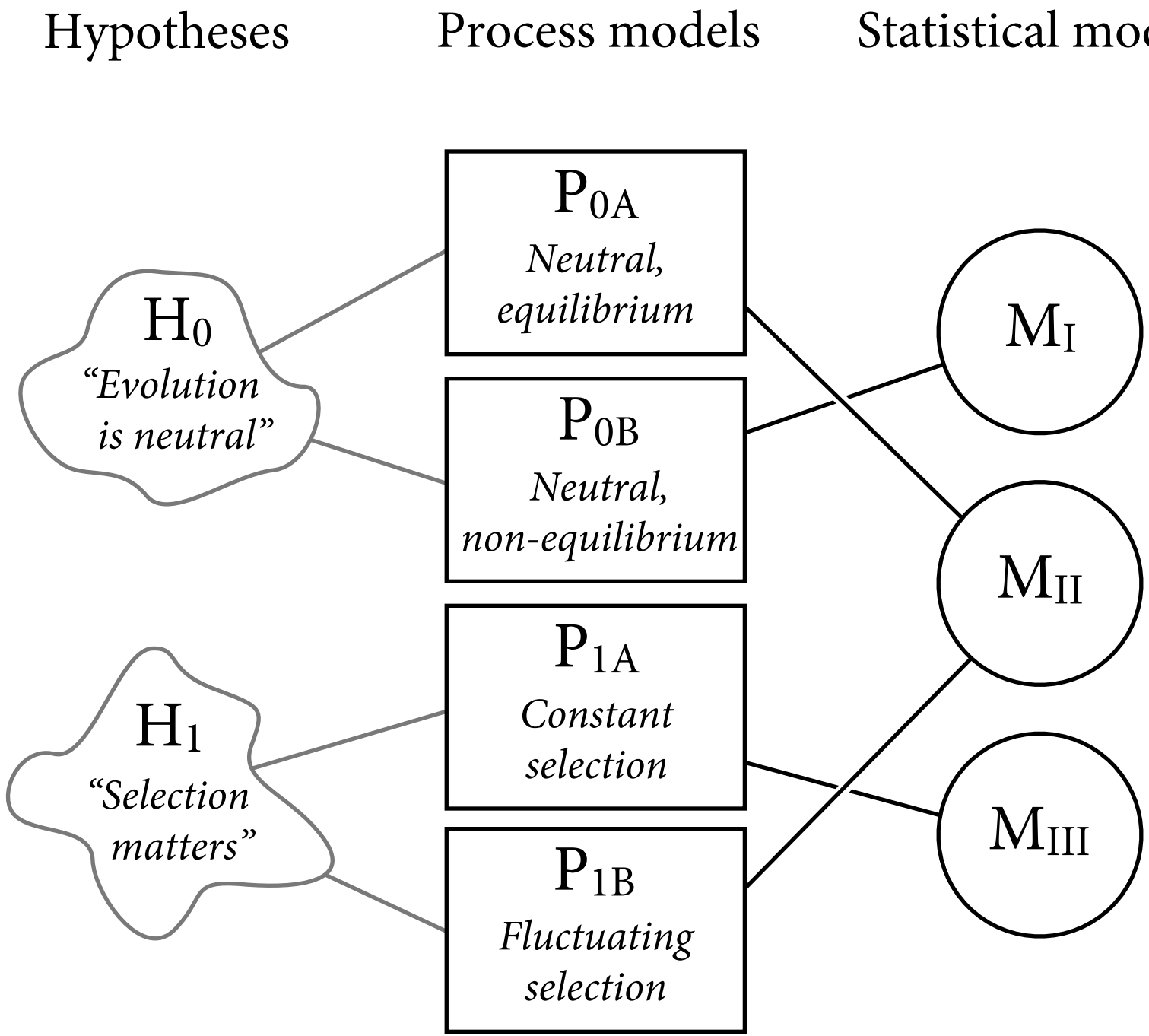

Hypotheses
Process models
Statistical models
H0
"Evolution is neutral"
H1
"Selection matters"
P0A
Neutral, equilibrium
P1A
Constant selection
P1B
Fluctuating selection
MII
MIII

Figure 1.2


Hypotheses
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H0
"Evolution is neutral"
H1
"Selection matters"
P0A
Neutral, equilibrium
P0B
Neutral, non-equilibrium
P1A
Constant selection
P1B
Fluctuating selection
MI
MII
MIII

Figure 1.2

Failure of Falsification

- Null models not unique
- Should falsify *explanatory* model, not *null* model
- Falsification is *consensual*, not *logical*
- Falsifiability about *demarcation*, not method
- No statistical procedure sufficient
- Science is social technology

"There is even something like a methodological justification for individual scientists to be dogmatic and biased. Since **the method of science is that of critical discussion**, it is of great importance that the theories criticized should be tenaciously defended. For only in this way can we learn their real power."

—Karl Popper, *The Myth of the Framework*

Golem Engineering

- Need a framework for developing and vetting statistical golems
- Several options
- We'll use this one
  - Bayesian data analysis
  - Multilevel modeling
  - Model comparison

From *Breath of Bones: A Tale of the Golem*

Bayesian data analysis

- Use *probability* to describe uncertainty
  - Extends ordinary logic (true/false) to continuous *plausibility*
- Computationally difficult
  - Markov chain Monte Carlo (MCMC) to the rescue
- Used to be controversial
  - Ronald Fisher: Bayesian analysis "must be wholly rejected."

Pierre-Simon Laplace (1749–1827)

Sir Harold Jeffreys (1891–1989) with Bertha Swirles, aka Lady Jeffreys (1903–1999)

Bayesian data analysis

Count all the ways data can happen, according to assumptions.

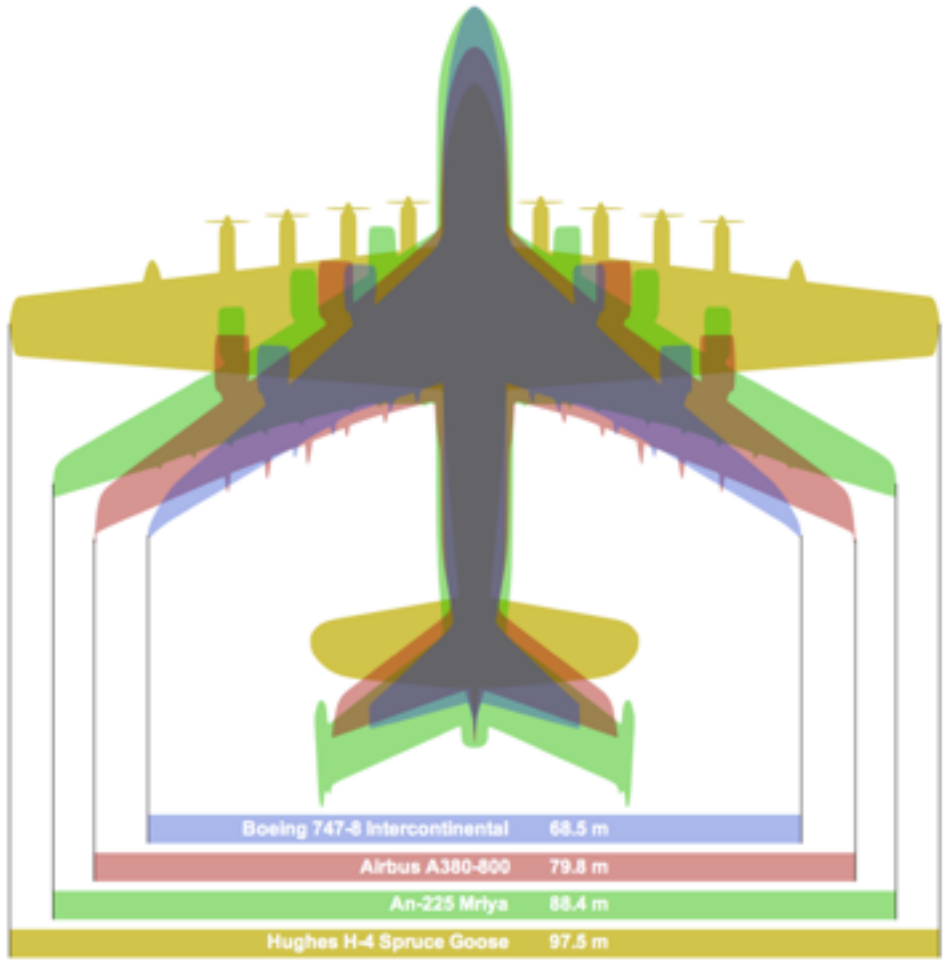
Assumptions with more ways that are consistent with data are more plausible.

Multilevel models

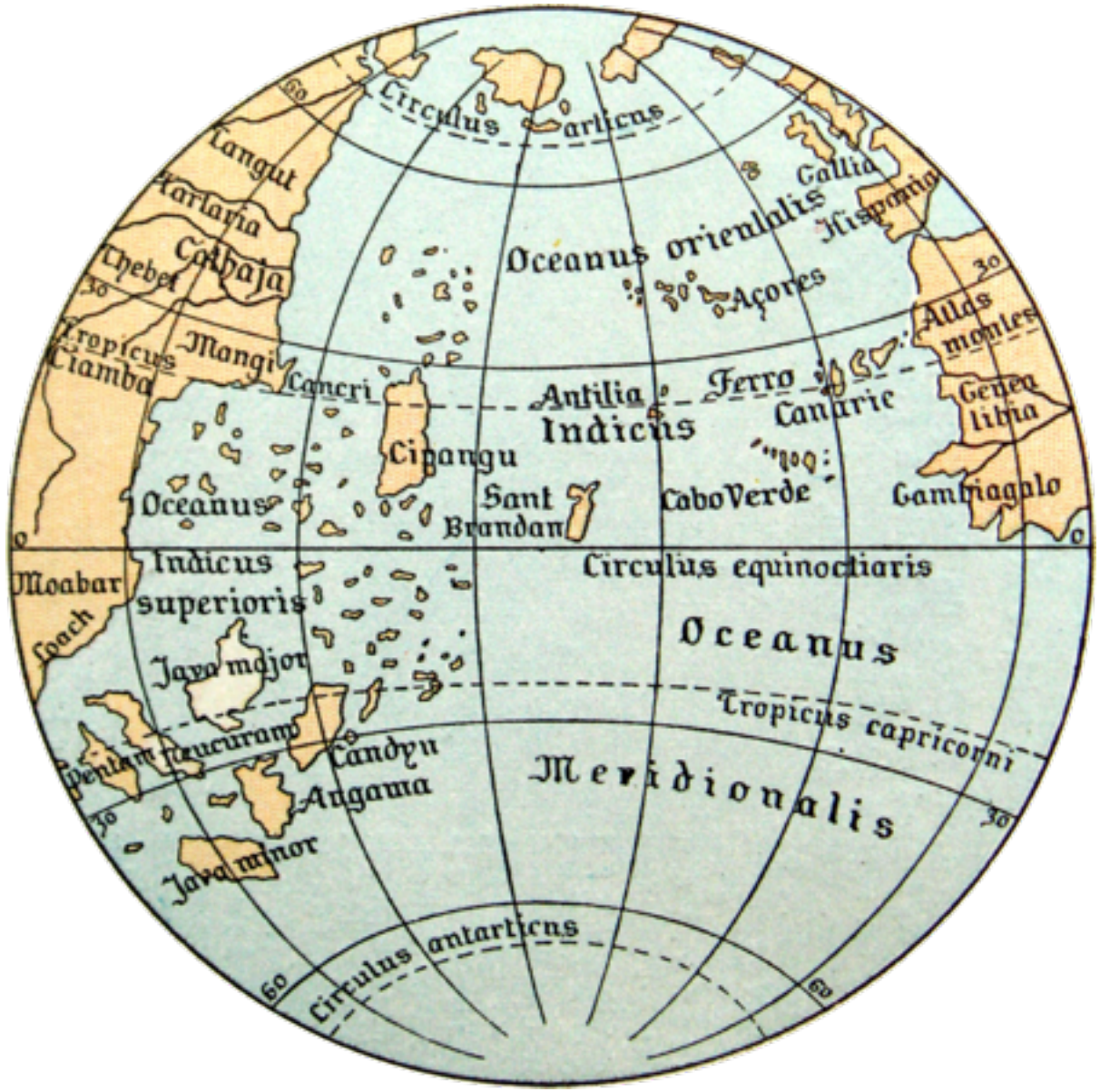
- Models with *multiple levels* of uncertainty
  - Replace parameters with models
- Common uses
  - Repeat & imbalanced sampling
  - Study variation
  - Avoid averaging
  - Phylogenetics, factor and path analysis, networks, spatial models
- Natural Bayesian strategy

Model comparison

- Instead of falsifying a **null** model, compare **meaningful** models
- Basic problems
  - Overfitting
  - Causal inference
- Ockham's razor is silly
- Information theory less silly
  - AIC, WAIC, cross-validation
- Must distinguish prediction from inference



Colombo's Mistake



Behaim's globe, as detailed in 1492

Colombo's Mistake

Behaim's globe, as detailed in 1492

Small and Large Worlds

- *Sensu* L.J. Savage (1954)
  - **Small world**: The world of the golem's assumptions. Bayesian golems are optimal, in the small world.
  - **Large world**: The real world. No guarantee of optimality for any kind of golem.
- Have to worry about both

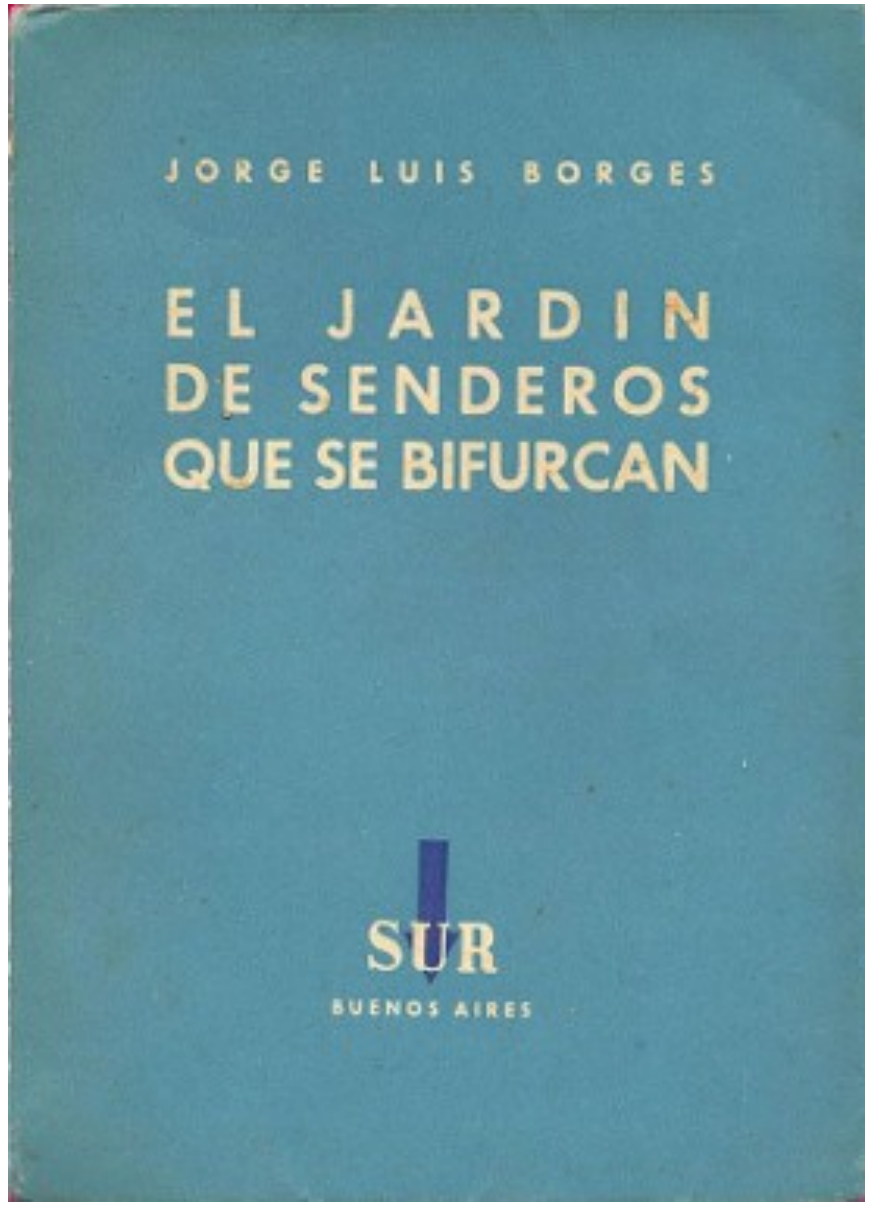
Bayesian data analysis

Count all the ways data can happen, according to assumptions.

Assumptions with more ways that are consistent with data are more plausible.

Garden of Forking Data

- The future:
  - Full of branching paths
  - Each choice closes some
- The data:
  - Many possible events
  - Each observation eliminates some



Garden of Forking Data

Contains 4 marbles

Possible contents:

(1) ○○○○

(2) ●○○○

(3) ●●○○

(4) ●●●○

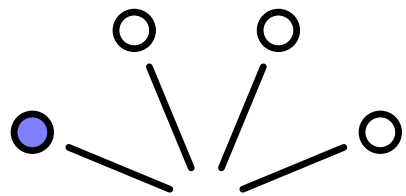
(5) ●●●●

Observe:

●○●

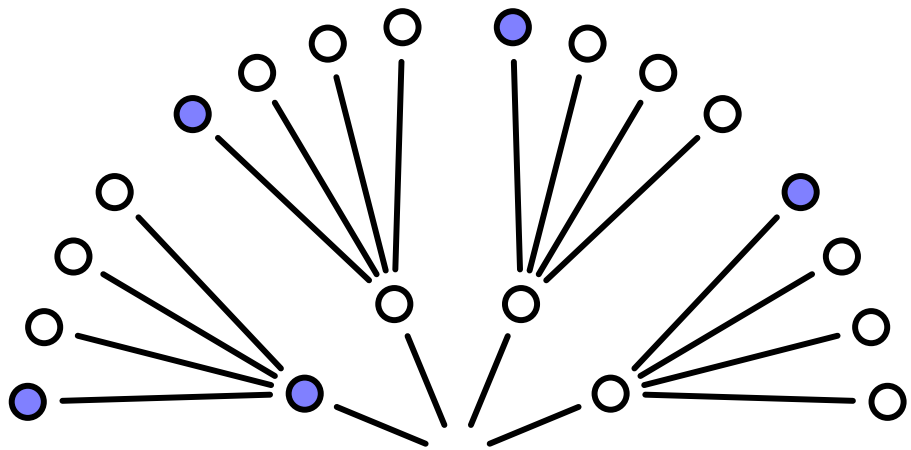
Conjecture:

Data:

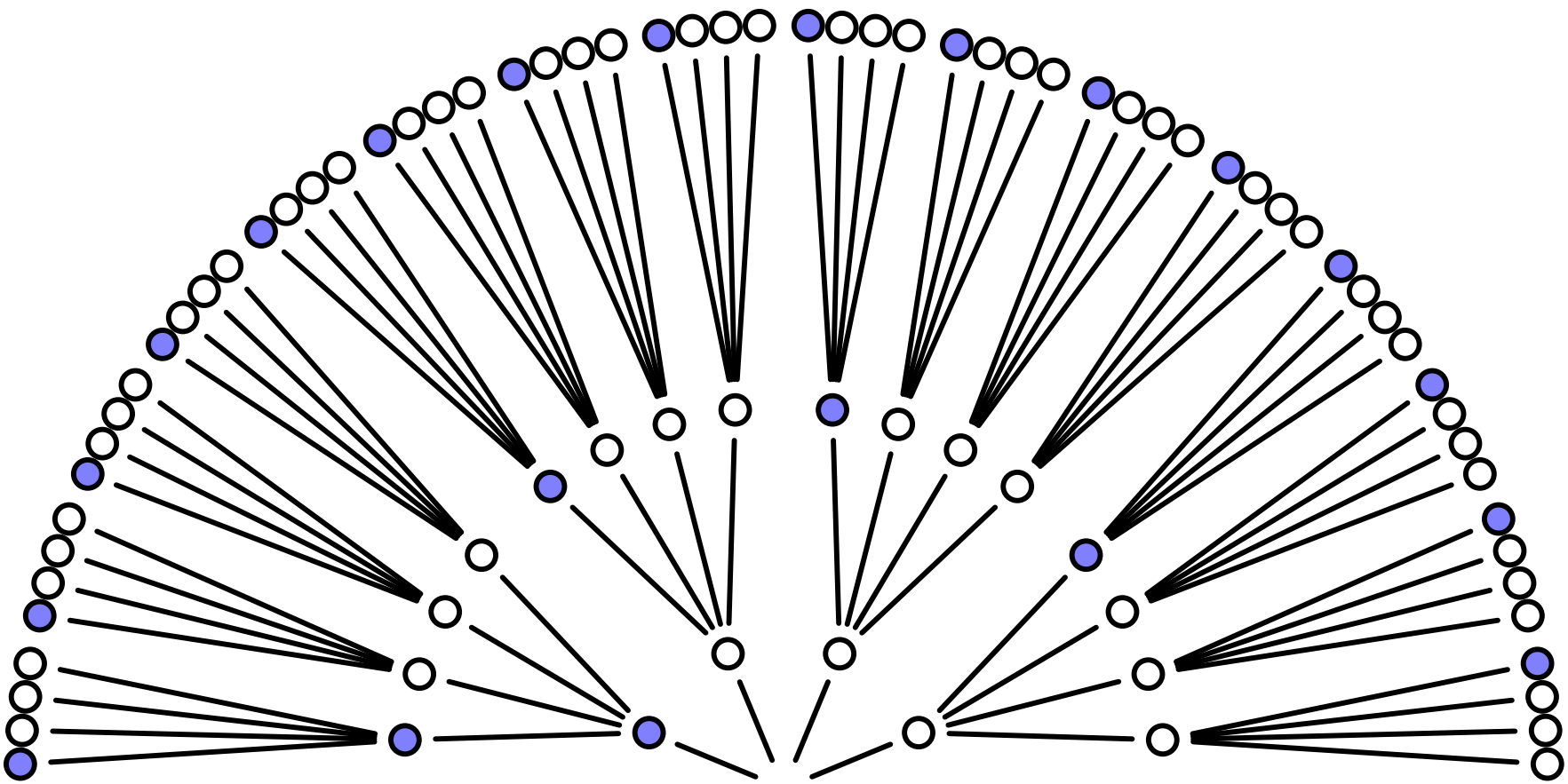


Conjecture:

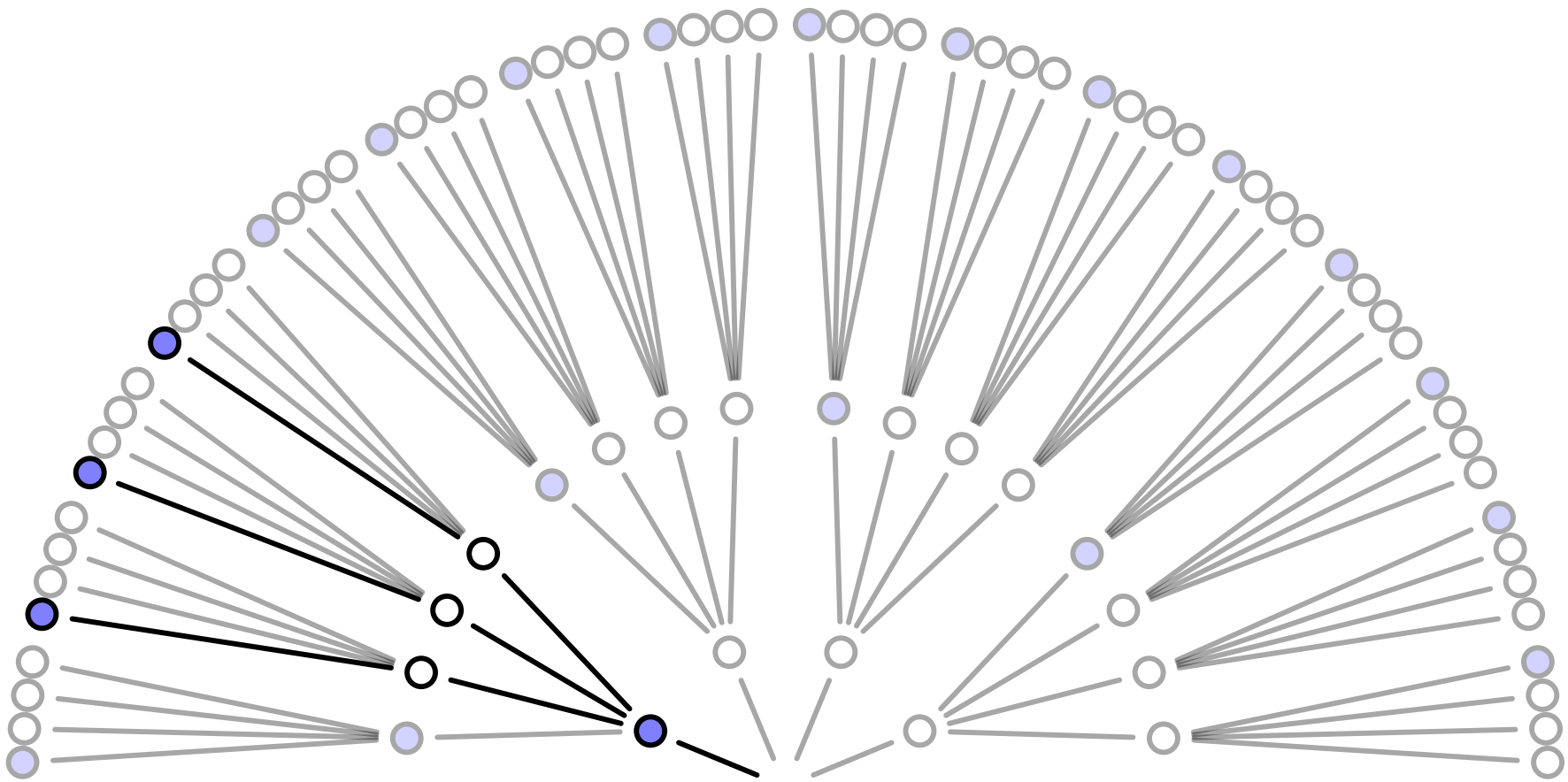
Data:



Conjecture: ●○○○ Data: ●○●



Conjecture: ●○○○ Data: ●○●



3 paths consistent with data

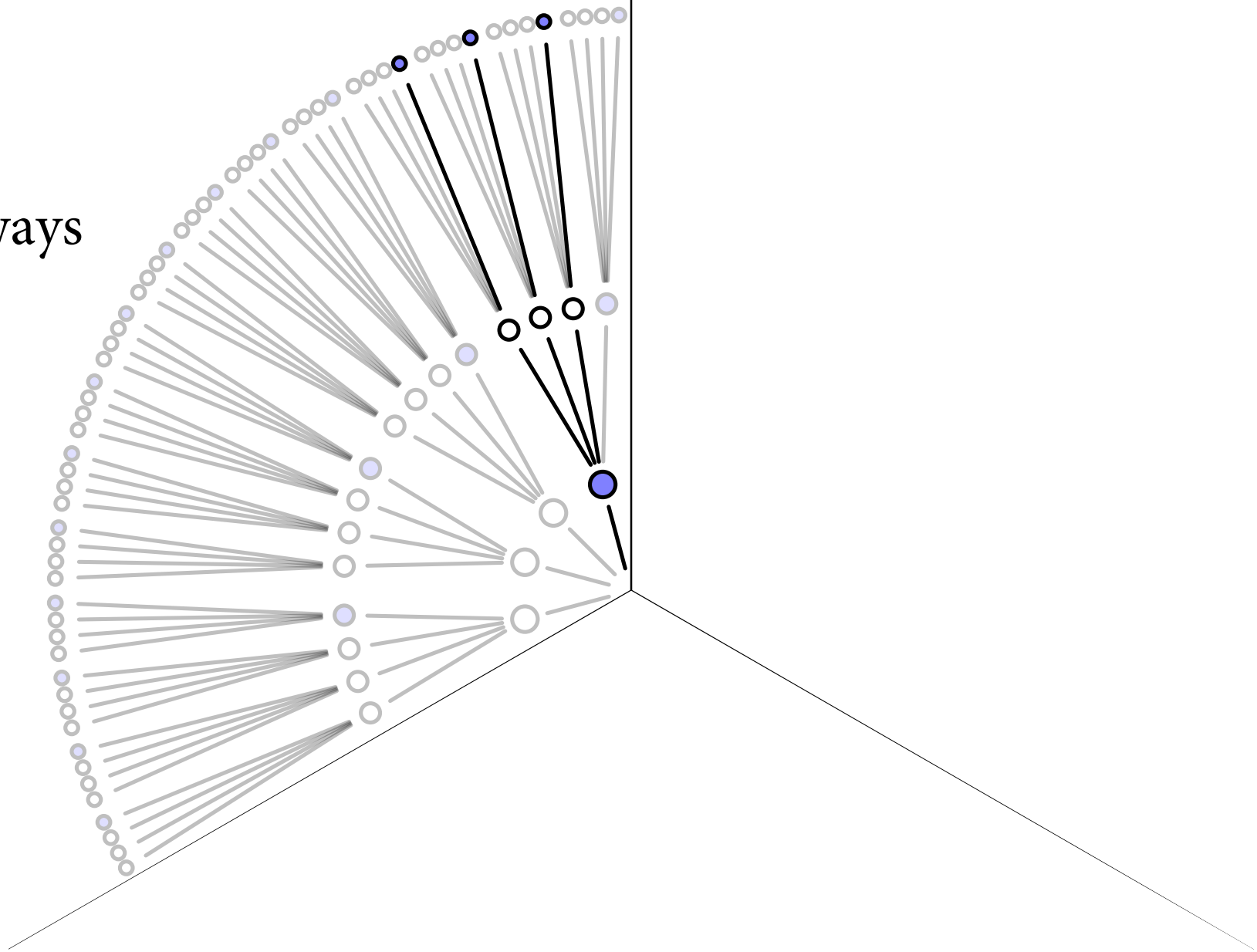
Garden of Forking Data

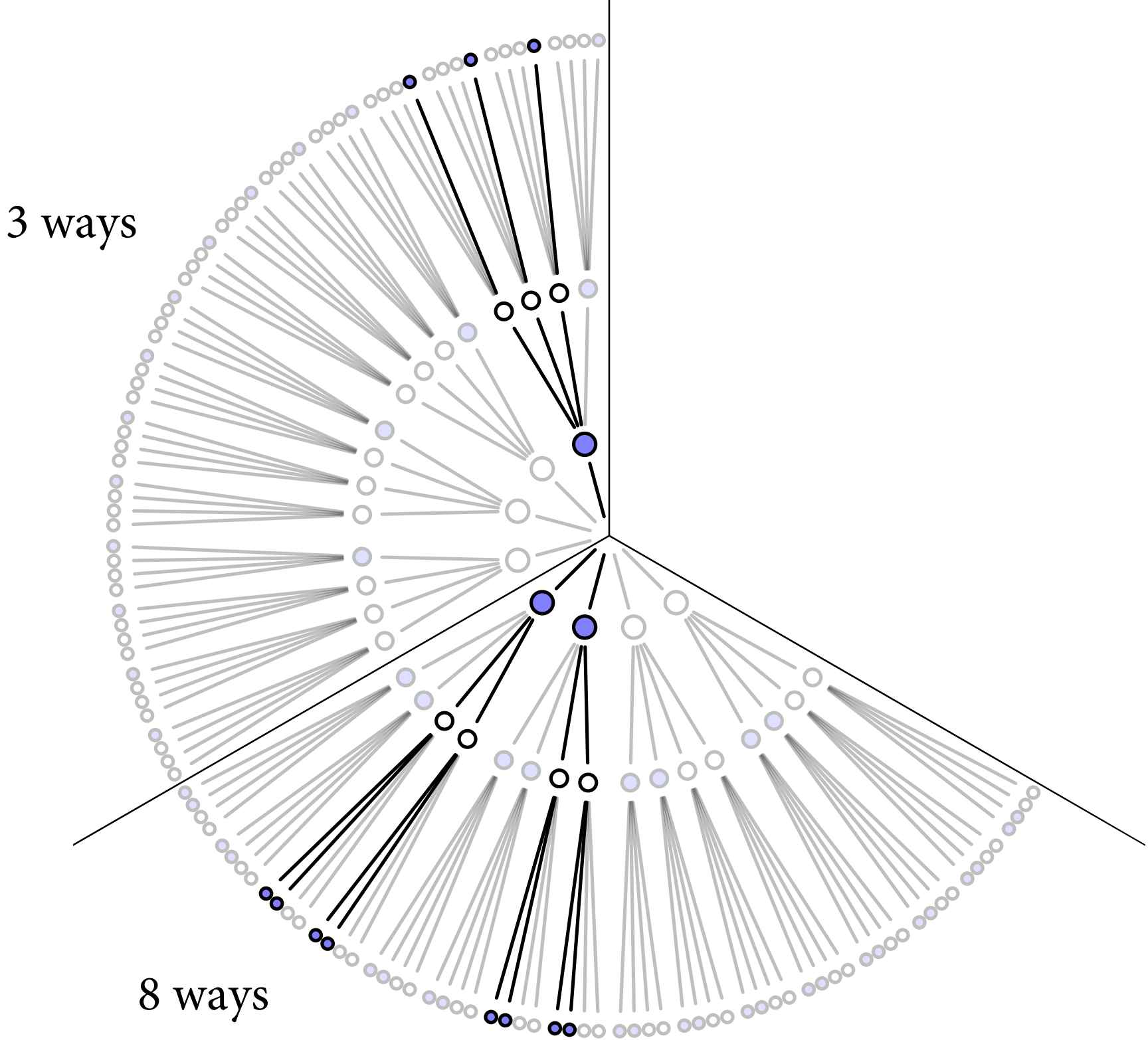
Possible contents:	Ways to produce ●○●
(1) ○○○○	?
(2) ●○○○	3
(3) ●●○○	?
(4) ●●●○	?
(5) ●●●●	?

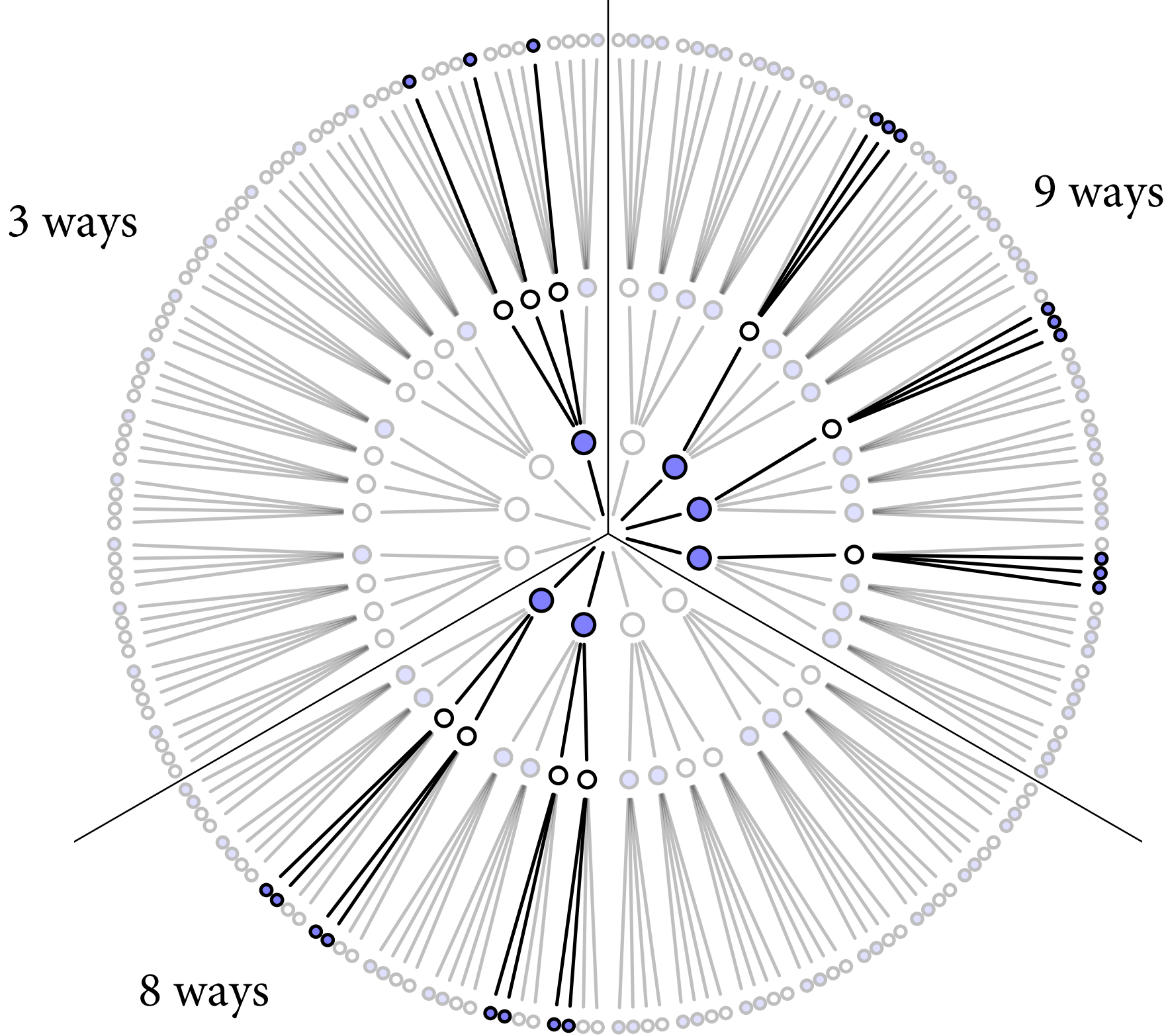
Garden of Forking Data

Possible contents:	Ways to produce ●○●
(1) ○○○○	0
(2) ●○○○	3
(3) ●●○○	?
(4) ●●●○	?
(5) ●●●●	0

3 ways

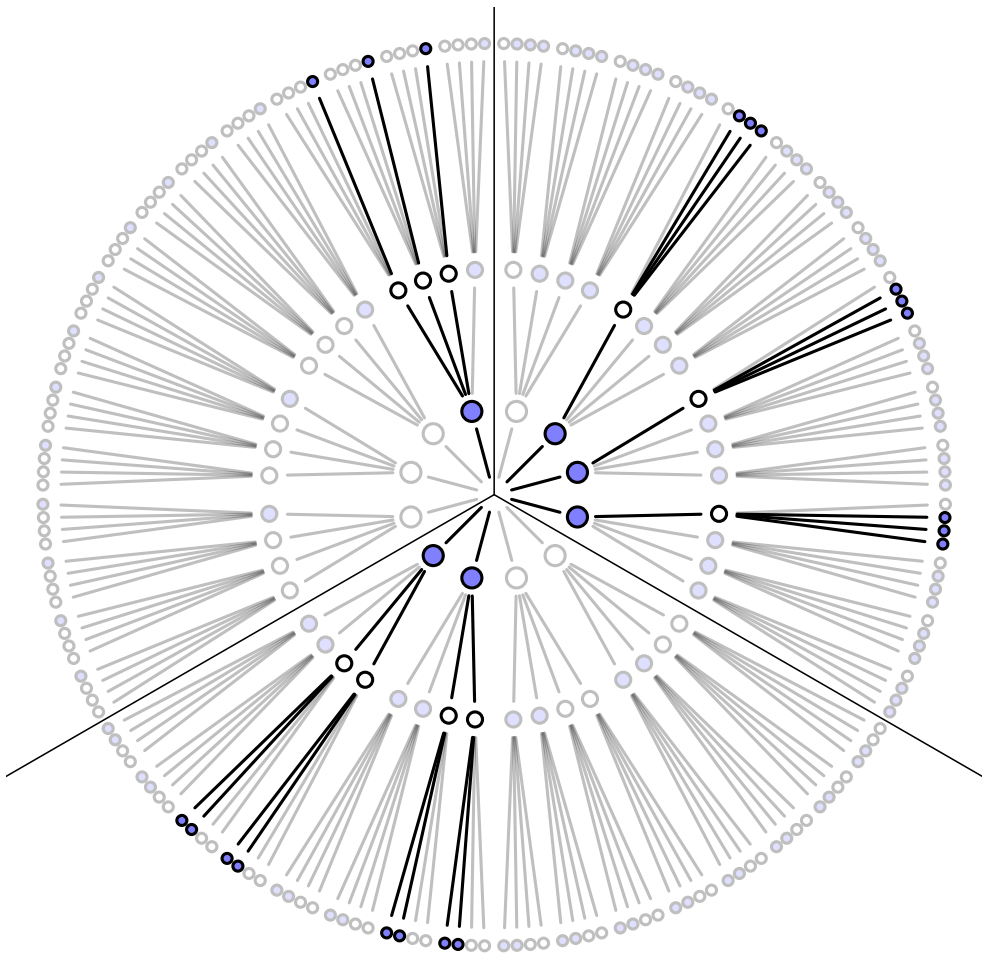



3 ways
8 ways


3 ways
9 ways
8 ways

Garden of Forking Data

Conjecture	Ways to produce ●○●
[○○○○]	$0 \times 4 \times 0 = 0$
[●○○○]	$1 \times 3 \times 1 = 3$
[●●○○]	$2 \times 2 \times 2 = 8$
[●●●○]	$3 \times 1 \times 3 = 9$
[●●●●]	$4 \times 0 \times 4 = 0$



Updating

Another draw from the bag: 

Conjecture	Ways to produce ●	Previous counts	New count
[○○○○]	0	0	$0 \times 0 = 0$
[●○○○]	1	3	$3 \times 1 = 3$
[●●○○]	2	8	$8 \times 2 = 16$
[●●●○]	3	9	$9 \times 3 = 27$
[●●●●]	4	0	$0 \times 4 = 0$

Using other information

Factory says: ● marbles rare, but every bag contains at least one.

Conjecture	Factory count
[○○○○]	0
[●○○○]	3
[●●○○]	2
[●●●○]	1
[●●●●]	0

Using other information

Factory says: ● marbles rare.

Conjecture	Prior ways	Factory count	New count
[○○○○]	0	0	$0 \times 0 = 0$
[●○○○]	3	3	$3 \times 3 = 9$
[●●○○]	16	2	$16 \times 2 = 32$
[●●●○]	27	1	$27 \times 1 = 27$
[●●●●]	0	0	$0 \times 0 = 0$

Counts to plausibility

Unglamorous basis of applied probability:

Things that can happen more ways are more plausible.

Possible composition	p	ways to produce data	plausibility
[○○○○]	0	0	0
[●○○○]	0.25	3	0.15
[●●○○]	0.5	8	0.40
[●●●○]	0.75	9	0.45
[●●●●]	1	0	0

Counts to plausibility

Possible composition	p	ways to produce data	plausibility
[○○○○]	0	0	0
[●○○○]	0.25	3	0.15
[●●○○]	0.5	8	0.40
[●●●○]	0.75	9	0.45
[●●●●]	1	0	0

R code 2.1

```
ways <- c( 3 , 8 , 9 )
ways/sum(ways)
```

```
[1] 0.15 0.40 0.45
```

Counts to plausibility

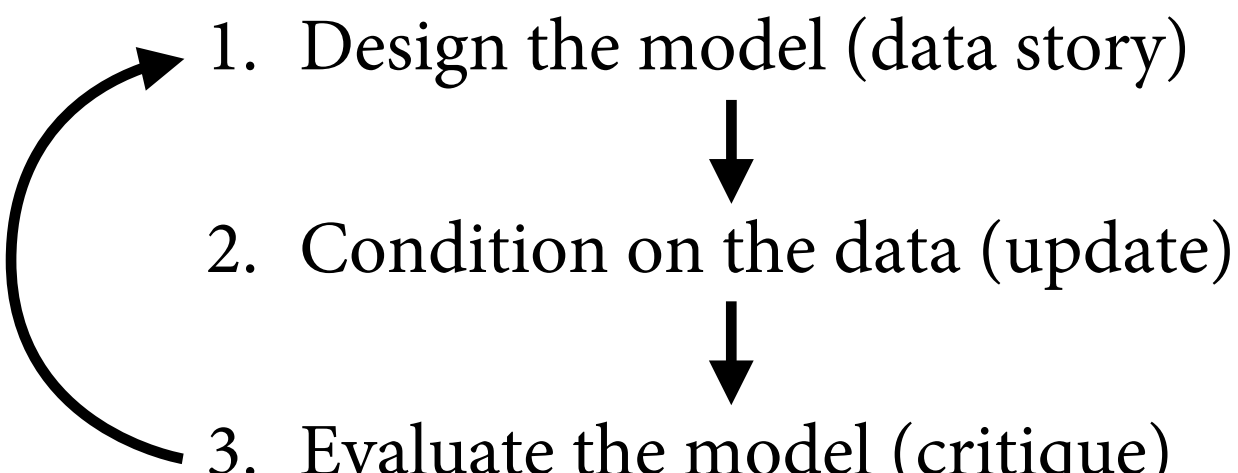
Possible composition	p	ways to produce data	plausibility
[○○○○]	0	0	0
[●○○○]	0.25	3	0.15
[●●○○]	0.5	8	0.40
[●●●○]	0.75	9	0.45
[●●●●]	1	0	0

Plausibility is *probability*: Set of non-negative real numbers that sum to one.

Probability theory is just a set of shortcuts for counting possibilities.

Building a model

- How to use probability to do typical statistical modeling?



Nine tosses of the globe:

W L W W W L W L W