IRTrees for eye tracking

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Based on research in collaboration with
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Process data
- direct process data:
data on *activities while working on a problem*
- indirect process data:
data with relevance to inferences regarding *activities while working on a problem*
often these are parallel data: response times, brain activation fMRI data, EEG data, introspective questions

Process models
Models fitting with a process narrative
based on direct or indirect process data

The models to be presented are
- dynamic models for direct process data
they are extremely intensive longitudinal data
- they fit with a process narrative because they are tree models

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- dynamic models for direct process data
they are extremely intensive longitudinal data
- they fit with a process narrative because they are tree models

Which does not prove they capture real ongoing processes

we are stretching model complexity
testing the limits

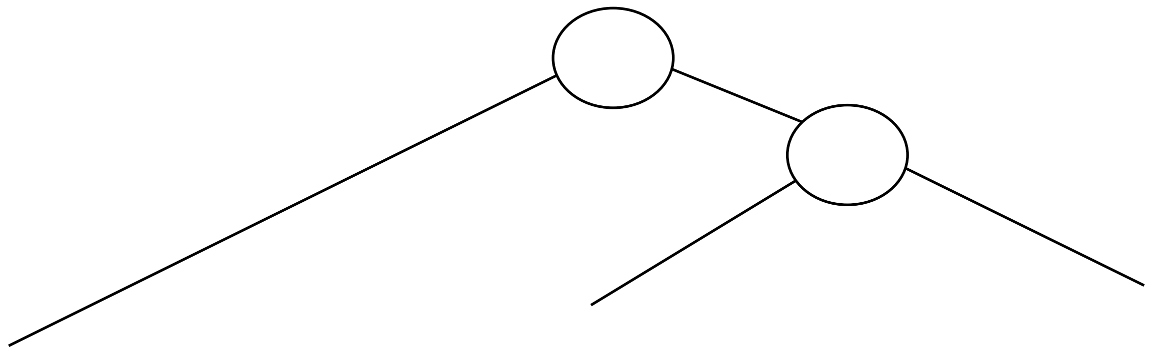
to isolate the gravity effect
in the paths of for falling leafs
on a windy November day

IRTree models

response tree models
item response tree models

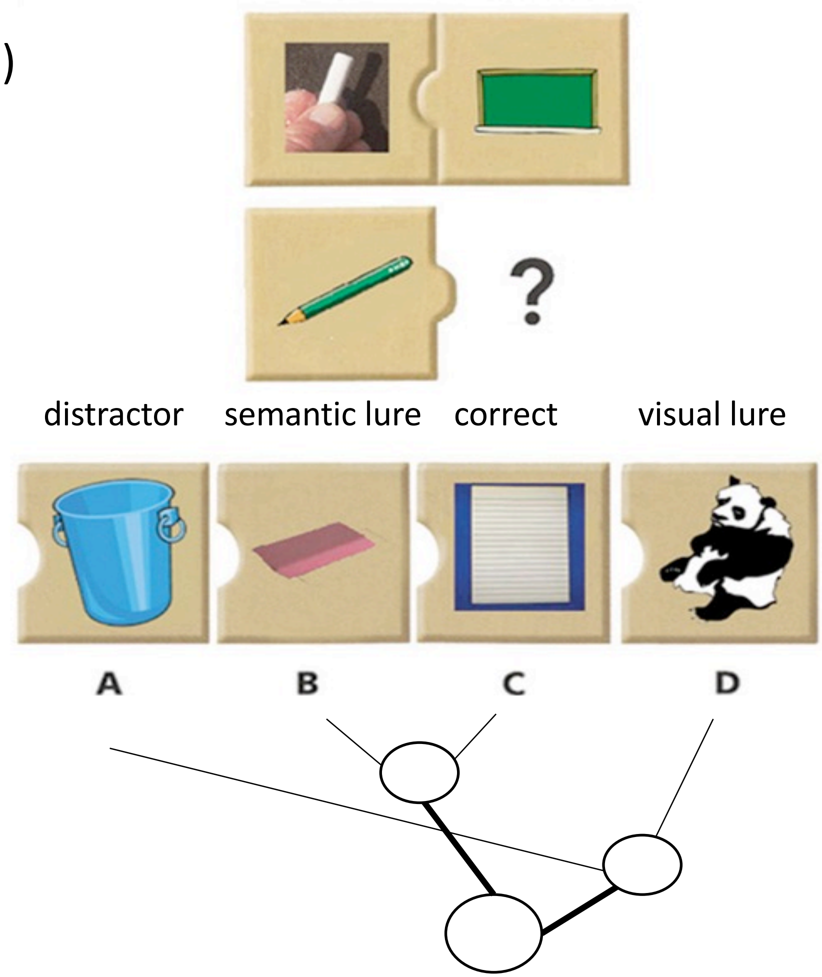
- extensions of discrete survival (frailty) models
- multinomial processing tree models from cognitive psychology, with random effects (Batchelder)
- have been used to model missing responses (Cees Glas)
- general formulation in psychometric literature Böckenholt (2012), De Boeck & Partchev (2012), Roe-Thissen & Thissen (2013)

Examples

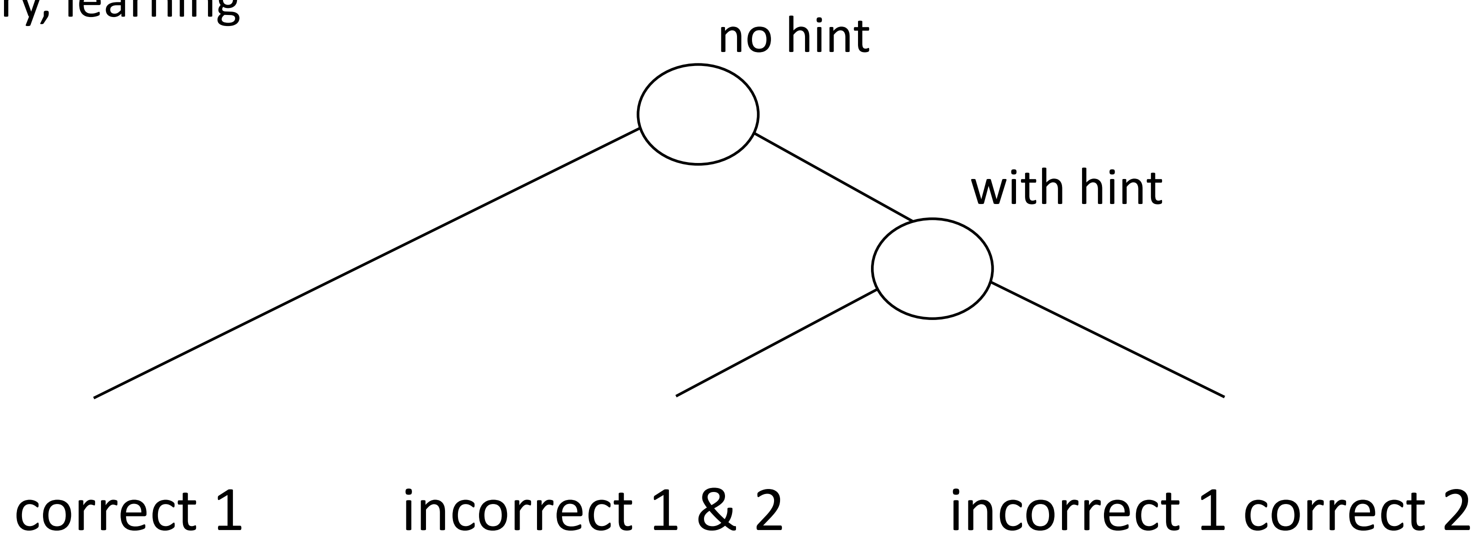


oatmeal bacon waffles

Wright, .., Bunge (2008)
Neural correlates of
fluid reasoning



Problem solving with and
without a hint
retry, learning



A Node 1 response is a subset of possible responses
for example, “not oatmeal”

All other Node responses are *conditional responses,*
responses given a condition is fulfilled
for example, the Node 2 response “bacon” is a conditional response, a response conditional on “not oatmeal”

Trees can represent the response structure one is interested in
Only binary trees are considered (can be extended)

The conditional coding is the only one that does not induce dependency between the response options

Conditional coding

option 1	0	-
option 2	1	0
option 3	1	1

option 1	0	0	-
option 2	0	1	-
option 3	1	-	0
option 4	1	-	1

missingness is MAR

The task

Speaker instructs listener

"Click on the small … envelope"

N= 152 (listeners)
96 items in 3 conditions
112 time points
(intervals of 10 millisec
between 180 and 1300ms
following the onset

pipe	**large envelope**	dog
balloon	X	car
small envelope	house	**small elephant**

pipe **large envelope** dog

balloon X car

house

Node 1 = 0

Node 2 = NA

The task

Speaker instructs listener

"Click on the small … envelope"

small envelope

small elephant

Node 1 = 1

Node 2 = 0 or 1

The task

Speaker instructs listener

"Click on the small … envelope"

small elephant

Node 1 = 1

Node 2 = 0

The task

Speaker instructs listener

"Click on the small … envelope"

small
envelope

Node 1 = 1

Node 2 = 1

Conditions in experiment

- One contrast
- Two contrasts shared
- Two contrasts privileged

One contrast

N	**C**	**L**
D	**X**	**T**
T	**E**	**F**

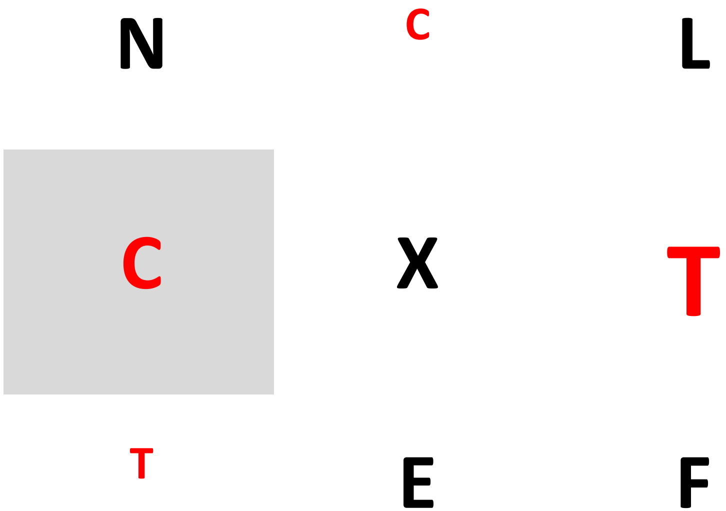
"Click on the small … T"

Two contrasts shared

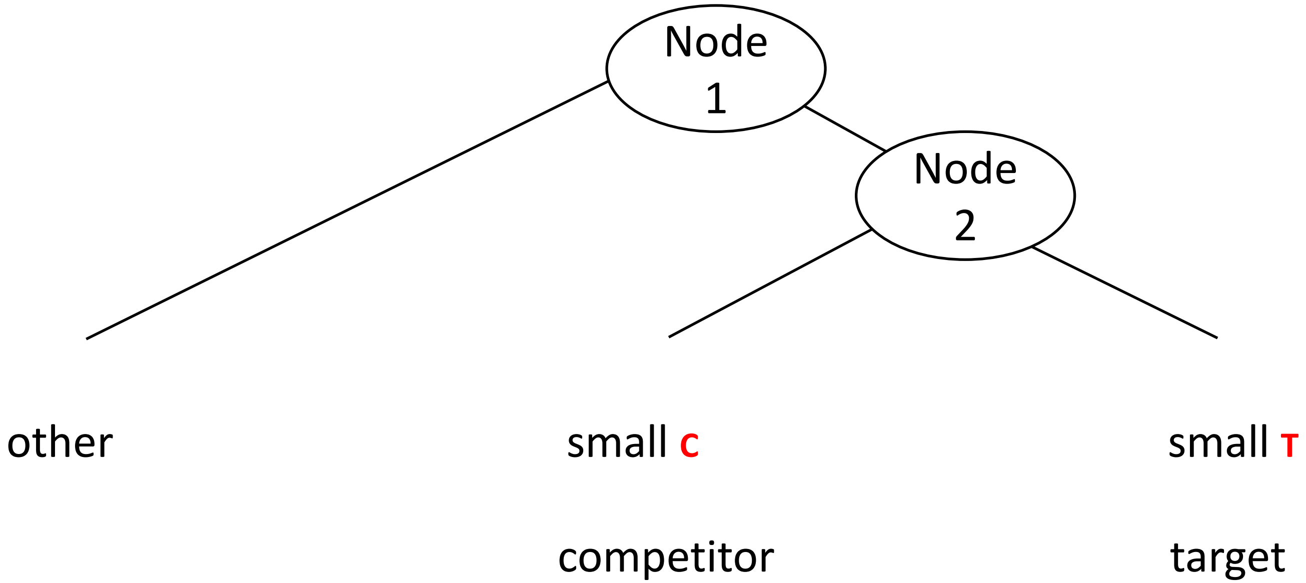
N	C	L
C	X	T
T	E	F

"Click on the small … T"

Two contrasts privileged



"Click on the small … T"
listener is told that speaker does not see the large C


Node 1
Node 2
other
small c
small T
competitor
target

Coding of eye fixation on

	Node 1	conditional response Node 2
other	0	-
competitor	1	0
target	1	1

Main interest are the fixed effects of condition
coding of conditions:
- one contrast (-1) vs two contrasts shared (0.5) & two contrasts privileged (0.5)
- one contrast (0) and two con (-0.5) vs two con privileged (0.5)

Additional fixed effects
- trend
- autoregressive effects

to avoid bias in main interest estimates and standard errors

Random effects for persons and items

Three important aspects

1. Node specificity of effects
   Everything can be different between the nodes
   including multidimensionality across nodes

2. Nodes combined with random effects
   issue of selecting random effects

3. Nodes combined with time series
   two parallel series: *Node 1* and *Node 2*
   missing observations for *Node 2*

1. Node specificity of effects

- Stronger positive trend for Node 2?
- Multidimensionality: a different dimension per node?
- Do condition effects depend on the node?

- Stronger positive trend for Node 2? YES
- Multidimensionality: a different dimension per node? YES, but …
- Do condition effects depend on the node? YES

- Upward trend is steeper
  for within-category disambiguation
  than for category identification
  0.031 vs 0.005
- Node 2 is a different ability compared with
  Node 1
  r = 0.414

Condition effects

Preliminary on semantics and pragmatics

Two effects based on *semantics*

- commonality
- contrast

One effect based on *pragmatics*

- knowing the conversation context
  and given perspective taking

The *two-contrasts conditions favor* Node 1

T **C**

T **c**

"small" is a
common contrast
feature of the two bottom letters

	Node 1	Node 2
two vs one	**0.074** (0.014)	-0.370 (0.035)
two priv vs shared	-0.006 (0.021)	0.066 (0.048)

The *one-contrast condition* favors Node 2

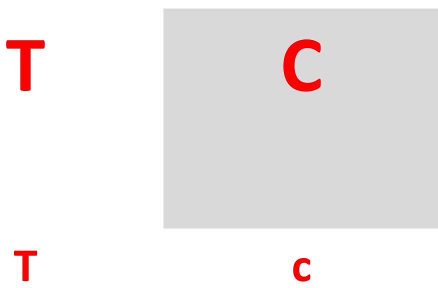
T

T C

“small” is a
unique contrast
feature of the left bottom letter

	Node 1		Node 2
two vs one	**0.074** (0.014)	↔	**-0.370** (0.035)
two priv vs shared	-0.006 (0.021)		0.066 (0.048)

The *privileged two-contrast condition* favors Node 2



“small” is a
common contrast
feature of two letters
but unique in the conversation
context if perspective taking

	Node 1	Node 2
two vs one	0.074 (0.014)	-0.370 (0.035)
two priv vs shared	-0.006 (0.021)	**0.066** (0.048)

remember

2. Nodes combined with random effects

Even more random effects

Random effect selection issues: power, bias

- Minimal approach
  plus forward strategy
- Maximal approach
  plus backward strategy
- Structured search
- Sensitivity analysis focused on effects of interest

- Step 1: are nodes multidimensional?
- Step 2: if they are, then
  investigate model fit for random AR for persons, items, persons & items per node
- Step 3: test effects of interest with
  different choices for random effects

3. Nodes combined with time series

Autoregression and cross-lagged relationships for
- two time series
- missingness in the second time series

two times two series

Nodes 1 and 2

X_1 : binary variable for N1 response

$X_1 = 1$ if T or C fixation (Node 1), 0 otherwise

X_2 : binary variable for conditional response (Node 2)

$X_2 = 1$ if T fixation, 0 if C fixation, missing if other

X_T : binary variable for target fixation,

$X_T = 1$ for T fixation, 0 otherwise

X_C : binary variable for competitor fixation,

$X_C = 1$ for C fixation, 0 otherwise

X_T	0	1	0	0	1	0	1	1	0	0	0
X_C	0	0	0	0	0	1	0	0	1	0	1
X_{N1}	0	1	0	0	1	1	1	1	1	0	1
X_{N2}	-	1	-	-	1	0	1	1	0	-	0

dynamic modeling which captures same information as AR1 and cross-lagged dependencies:

$AR1_{T \rightarrow N1\ (t)}$: regression of $X_{N1(t-1)}$ on $X_{T(t-1)}$
$AR1_{C \rightarrow N1\ (t)}$: regression of $X_{N1(t-1)}$ on $X_{C(t-1)}$

$AR1_{T \rightarrow N2\ (t)}$: regression of $X_{N2(t-1)}$ on $X_{T(t-1)}$
$AR1_{C \rightarrow N2\ (t)}$: regression of $X_{N2(t-1)}$ on $X_{C(t-1)}$

Fixed effects

$AR1_{T \rightarrow N1\ (t)}$	4.347
$AR1_{C \rightarrow N1\ (t)}$	4.024
$AR1_{T \rightarrow N2\ (t)}$	2.648
$AR1_{C \rightarrow N2\ (t)}$	-2.629

Random effects

$AR1_{T \rightarrow N1\ (t)}$	0.114			
$AR1_{C \rightarrow N1\ (t)}$	0.748	0.340		
$AR1_{T \rightarrow N2\ (t)}$	0.140	0.004	0.131	
$AR1_{C \rightarrow N2\ (t)}$	-0.464	-0.515	0.788	0.247

Afterthoughts

- A case study of complex modeling of complex data
- A conditional response approach can be helpful to extract information/effects one wants to focus on
  controlling for less relevant effects in the the background
- Remember the effect of two contrast privileged vs
  two contrast shared on Node 2 effect
  - Suppose there are individual difference in the effect (random person effects) ?
  – -- they would reflect a perspective taking ability

Complex can still be beautiful