Computational modelling of developmental disorders

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Build a model

Visual input

Frontal eye fields

REWARD SYSTEM

When should I change where I’m looking? (I get bored)

Where should I look next? (I want to see something interesting)

Learn to fixate rewarding objects (make use of where mummy is looking?)

Developmental trajectory of the model

Emergence of Gaze following

Triesch et al. (2006)

Reinforcement learning: State-action tables (networks)

Table 1: A state-action table for the Wilson model

<table>
<thead>
<tr>
<th>Action</th>
<th>Frontal fixation</th>
<th>Visual fixation</th>
<th>Frontal fixation with fixation</th>
<th>Visual fixation with fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Visual</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Richardson & Thomas (2006)

Sample sequences of actions

Triesch et al. (2006)
Normal vs. Atypical?

- We have a normal model of development
  - Not uncontroversial (e.g., Csibra, 2006)
- What if this system lies within an individual with a developmental disorder?
  - Autism
    - Disinterest in social contact / faces
    - Dyadic interactions observed to be atypical in young children with autism
  - Williams syndrome
    - Elevated interest in faces
    - Triadic interactions observed to be atypical in toddlers with WS

Atypical development

- Autism: Reduce reward of face
- Williams syndrome: Increase reward of face

Generate predictions: ADHD

- ADHD (Williams & Dayan, 2005):
  - Reduced discounting rate
  - Too exploratory?
  - Slow reward learning?
- Prediction
  - Infant precursor of ADHD may be delayed gaze following (but normal interest in faces)

Modelling in the study of developmental disorders

- Connectionist models of cognitive development
- Another case study – Specific Language Impairment
- Theoretical issues:
  - Where do modules come from?
  - Can I really developmentally damage a single module?
- Conclusions

Mechanisms of change

- Developmental psychology cannot simply comprise a list of behaviours that children show at each age
- It must identify mechanisms of change
- Use of computational modelling: implemented learning systems suggest possible mechanisms of change to drive formation of developmental theories
- Trying to “imagine” how knowledge is acquired has produced very nativist theories…

"Build it, and they will come."
"Build it, and they will come."
**Connectionism**

- Connectionist models use computational principles abstracted from neural computation
- Produce COGNITIVE level theories
- (a weakening of functionalism)

**Background**

- “[With regard to connectionism] … nativism, associationism, empiricism, rationalism, reductionism, genetics, computer science, neuroscience, linguistics, ethology, and the mind/body problem (and I may have forgotten a few) have all somehow involved themselves in what started as just a psychologist’s choice between theories of cognitive architecture.” - Fodor (2000)

**Connectionist models of development**

- Demonstration of implemented systems
- Simulation of data
- Viability of theoretical proposals:
  - Stages from continuous change
  - Developmental lags from graded representations
  - Rule following behaviour from associative systems
- Models don’t prove these are correct explanations
- Do widen candidate inferences from data
Domains of application

- **Infancy**: categorisation, object-directed behaviour, memory
- **Childhood**: Piagetian reasoning tasks (balance scale problem, sensori-perception), development of semantics
- **Language acquisition**: categorisation of speech sounds, segmentation of the speech stream into words, word learning and vocabulary development, inflectional morphology, syntax, metaphor, reading

### Outstanding issues

<table>
<thead>
<tr>
<th>Category</th>
<th>Feature 1</th>
<th>Feature 2</th>
<th>Feature 3</th>
<th>Feature 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning</td>
<td>Quality</td>
<td>Level</td>
<td>Rate</td>
<td>Recovery</td>
</tr>
<tr>
<td>Development</td>
<td>Stages</td>
<td>Developmental</td>
<td>Rate</td>
<td>Recovery</td>
</tr>
</tbody>
</table>

### Developmental disorders

- Selective genetic developmental deficits most theoretically interesting
  - SLI
  - Dyslexia
  - Williams syndrome
  - Autism

### Explanatory framework

- Explanations of deficits must be in terms of learning systems
- Learning systems in disorders have unusual properties that prevent normal acquisition
- Appropriate explanation is not in terms of focal damage to normal system but atypical constraints on plasticity

### Understanding the developmental process

- The developmental process must be central to understanding of developmental disorders
  (Karmiloff-Smith, 1998)
- How can we explore the “developmental process”?
3-layer feedforward network

Network parameters
- Models contain CONSTRAINTS which affect their ability to learn
  - Architecture
  - Activation dynamics
  - Representations
  - Learning algorithm
  - Training regime
- Neurocomputational properties may be influenced by genetic differences

Modelling disorders
- Assume a normal model
- Explore which parameter changes to the STARTSTATE lead to atypical trajectories and endstate deficits
- Use to assess viability of empirically driven hypotheses

The modelling enterprise
- Specific models
  - Test hypotheses in a particular domain using as many empirically driven constraints as possible
- Abstract models
  - Expand the range of candidate inferences from behaviour to structure
    - E.g., models used to assess the claim that double dissociations must arise from damaging modular systems
    - "This kind of behaviour can be produced by these kinds of system"

A specific model
- English past tense
  - Talk-talked
  - Wug-wugged "Rule"
  - Hit-hit
  - Sing-sang Exceptions
  - Go-went
  - Over-regularisation errors ('I thoughted it')
  - Omission errors ('yesterday, I talk to John')

Early excitement (sells books)
- Pinker (1999)
  - SLI = 'loss of certain genes [interferes] with the development of ... the ability to inflect new and uncommon regular verbs' => Regular Deficit
  - WS = memory mechanism for storing exception verbs is specifically impaired => Exception Deficit
  - WS + SLI = "a genetic double dissociation ... the first group of children rarely generalise the regular pattern; the second group of children generalise it freely"
Some data

Empirical and simulation data for past tense deficits in SLI

Study development...

Empirical and simulation data for past tense deficits in SLI

Is residual performance due to lexical memory?

Assumption: Frequency effects are hallmark of memory systems. Absence of frequency effects implicates a rule

Vary learning properties of an implemented developmental model

/sent/

/send/

(Joanisse & Seidenberg, 1999)
Empirical and simulation data for past tense deficits in SLI

English past tense model: Atypical developmental constraints

Simulation: Frequency effects

Simulation: Decrease following lesion to lexical-semantic

An Abstract model

- Addressing a theoretical issue on how the cognitive system develops

Animal studies

Huffman et al. (1999): reduce cortical sheet – what functional areas develop?
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Kahn & Krubitzer (2002): change input

Where do modules come from?

Where do modules come from?

Reading

Developmental Surface Dyslexia

Origin of modules

“Don’t look at me like that, Brad. I just don’t get it…”

“How do the bits know what to do in the first place?”

“What stops the bits from compensating for each other when one is damaged?”

“My God, Brad, how can a specific deficit for reading be inherited – when reading is a recent cultural invention?”
Origin of modules

Learn a problem with two clear parts...

Emergent specialisation of function of the two parts to two routes

If one component is initially damaged, does other still develop normally?

When would some components develop normally while others are damaged?

- Some developmental conditions for **Residual Normality**
  - Strong structure function-correspondences
  - Strong competition
  - Early commitment
  - Guided specialisation
  - Restrictions on resources

Thomas & Karmiloff-Smith (2002)

Is this important, at all?

- “The implication is that one cannot understand what is wrong in the cognitive system of a child or adult with a developmental disorder on their basis of apparently normal vs. impaired behaviour, unless one has a developmental account of where the cognitive structures comes from”
The effect of Residual Normality (RN) on Behavioural impairments after selective damage to Indirect route.

Inferences and disorders

What is producing normal (intact) behaviour? [Reg]

Acquired deficit

- Normal process in Direct route
- Mix of Normal process in Direct route and residual process in damaged Indirect route

Developmental deficit

- Normal process in Direct route
- Atypical processes in both Direct and residual Indirect route after development

Does the dissociation imply independent underlying processes?

Acquired deficit

- Yes
- Yes

Developmental deficit

- Yes
- No

Three conclusions

- (1) Developmental disorders must be explained in terms of the developmental process itself
- (2) Implemented models allow detailed consideration of computational constraints operating on development
- (3) Models are a necessary intermediate step to relate behavioural deficits to neural substrate and genetic influences on its development

Inferences and disorders

- Independently developing modules
- Emergent modules

Input layer (90 units)

Output layer (100 units)

Direct Route

Indirect Route

Acquired deficit

- Impaired process in residual damaged Indirect route
- Predominantly impaired process in residual damaged Indirect route

Developmental deficit

- Impaired process in residual damaged Indirect route
- Atypical processes in both Direct and residual Indirect route after development

Dissociations in developmental disorders

- Inferences from impaired behaviour to underlying structure depend on having a developmental theory of the origins of the underlying structure
- Models help construct these theories