

## UvA-DARE (Digital Academic Repository)

### Neural syntax

Fitz, H.

**Publication date**  
2009

[Link to publication](#)

**Citation for published version (APA):**

Fitz, H. (2009). *Neural syntax*. [Thesis, fully internal, Universiteit van Amsterdam]. Institute for Logic, Language and Computation.

**General rights**

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

**Disclaimer/Complaints regulations**

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

---

# Contents

<b>Acknowledgments</b>	<b>xi</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Computational models in language acquisition . . . . .	1
1.2 Why neural networks? . . . . .	4
1.3 Thesis outline . . . . .	5
<b>2 Recursion in neural networks</b>	<b>9</b>
2.1 Introduction . . . . .	9
2.2 The computational power of neural networks . . . . .	10
2.2.1 Feed-forward networks . . . . .	10
2.2.2 Recurrent networks . . . . .	11
2.3 RNNs and string language learning . . . . .	14
2.3.1 Regular languages . . . . .	16
2.3.2 Context-free languages . . . . .	16
2.3.3 Context-sensitive languages . . . . .	18
Remark on backpropagation . . . . .	20
2.4 RNNs and complex sentence structure . . . . .	21
2.4.1 Recursive auto-associative memory . . . . .	22
RAAM applications, extensions, and limitations . . . . .	25
2.4.2 A subsymbolic parser for embedded clauses . . . . .	26
The plausibility of SPEC . . . . .	30
2.4.3 Simple recurrence and complex structure . . . . .	31
2.4.4 Structural processing with semantic constraints . . . . .	34
The effect of semantic constraints . . . . .	36
2.4.5 Increasing grammatical complexity . . . . .	37
Discussion of Christiansen's results . . . . .	39
2.5 Summary . . . . .	43

<b>3</b>	<b>The Dual-path model</b>	<b>45</b>
3.1	Limitations of the SRN approach . . . . .	45
3.1.1	Meaning . . . . .	45
3.1.2	Definiteness . . . . .	48
3.1.3	Symbolic generalization . . . . .	51
3.2	Features of the Dual-path model . . . . .	52
3.2.1	Separate pathways . . . . .	52
3.2.2	The WHAT-WHERE division . . . . .	53
3.2.3	Event semantics . . . . .	54
3.3	Dual-path model architecture explained . . . . .	55
3.3.1	Sequencing system . . . . .	55
3.3.2	Message-lexical system . . . . .	57
3.3.3	Event semantics-layer . . . . .	60
3.4	Production sample . . . . .	62
3.5	Model assumptions . . . . .	66
3.5.1	Learning assumptions . . . . .	66
	Learning-as-processing . . . . .	66
	Prediction error . . . . .	67
3.5.2	Architectural assumptions . . . . .	68
	Two pathways . . . . .	68
	SRN sequencing . . . . .	68
3.5.3	Representational assumptions . . . . .	68
	WHAT-WHERE separation . . . . .	68
	XYZ roles . . . . .	69
3.6	Past research with the Dual-path model . . . . .	70
<b>4</b>	<b>Learning</b>	<b>73</b>
4.1	Introduction . . . . .	73
4.2	Artificial language and method . . . . .	76
4.2.1	Artificial language . . . . .	76
4.2.2	Method . . . . .	79
4.3	Message representation comparison . . . . .	80
4.3.1	Random baseline . . . . .	80
4.3.2	Simple-event message . . . . .	81
4.3.3	Event-order message . . . . .	82
4.3.4	Event-link message . . . . .	88
4.3.5	Event-order-link message . . . . .	91
4.3.6	Binding message . . . . .	94
4.3.7	Topic-focus message . . . . .	96
4.3.8	Simple topic-focus message . . . . .	98
4.3.9	Summary message types . . . . .	100
4.4	The gapped element . . . . .	104
4.4.1	Ambiguities . . . . .	105

4.4.2	Acquisition . . . . .	106
4.4.3	Alternations . . . . .	108
4.4.4	Performance comparison <i>gap-link</i> versus <i>no gap-link</i> . . . . .	109
4.5	Discussion . . . . .	112
<b>5</b>	<b>Model analysis</b>	<b>115</b>
5.1	Behavioral analysis . . . . .	115
5.1.1	Syntactic alternations . . . . .	115
	Bigram statistics . . . . .	119
	Frequency of semantic roles . . . . .	120
	Error analysis . . . . .	121
5.1.2	Topic and focus . . . . .	123
5.2	Representational analysis . . . . .	128
5.2.1	Lexical categories . . . . .	129
5.2.2	Thematic role sequencing . . . . .	132
	Hierarchical planning . . . . .	136
5.2.3	Phrasal categories and argument structure . . . . .	138
	Linear discriminant analysis . . . . .	138
5.2.4	Verb, noun and prepositional phrases . . . . .	138
5.2.5	Argument structure . . . . .	143
5.2.6	Clause-level analysis . . . . .	153
	Principal components analysis . . . . .	153
	Clause type comparison . . . . .	154
<b>6</b>	<b>Generalization</b>	<b>161</b>
6.1	Introduction . . . . .	161
6.2	Knowledge transfer . . . . .	161
6.3	Extension of language and semantics . . . . .	163
6.4	Structural generalization . . . . .	165
6.5	Lexical generalization . . . . .	169
6.6	Right-branching versus center-embedding . . . . .	174
6.7	Recursive productivity . . . . .	184
6.7.1	Is recursion uniquely human? . . . . .	184
6.7.2	Recursion and productivity . . . . .	186
6.7.3	The innateness of recursion . . . . .	187
6.7.4	A proper <i>explanandum</i> . . . . .	188
6.7.5	Recursive generalization in the Dual-path model . . . . .	190
6.8	Conclusion . . . . .	200
<b>7</b>	<b>Learning polar interrogatives</b>	<b>203</b>
7.1	The general controversy . . . . .	203
7.1.1	The learning problem . . . . .	205
7.1.2	Three empirical hypotheses . . . . .	207

	7.1.3	Statistical learning . . . . .	212
		The Lewis & Elman model . . . . .	214
		The Reali & Christiansen model . . . . .	216
7.2		The recursive Dual-path model approach . . . . .	218
	7.2.1	Artificial language, semantics and method . . . . .	220
7.3		Modelling results . . . . .	222
	7.3.1	Simple polar interrogatives . . . . .	223
	7.3.2	Complex <i>wh</i> -questions . . . . .	224
		Error analysis . . . . .	226
	7.3.3	Bootstrapping . . . . .	230
7.4		Structure-dependence revisited . . . . .	237
	7.4.1	Hidden layer analysis . . . . .	241
		Hierarchical structure . . . . .	241
		Generalization by analogy . . . . .	244
		Questions and declaratives . . . . .	245
7.5		Discussion . . . . .	247
<b>8</b>	<b>The accessibility hierarchy</b>		<b>253</b>
8.1		Introduction . . . . .	253
8.2		The accessibility hierarchy in development . . . . .	257
8.3		The recursive Dual-path model approach . . . . .	258
8.4		Language and method . . . . .	259
8.5		The accessibility hierarchy in the recursive Dual-path model . . . . .	260
	8.5.1	The S>A contrast . . . . .	261
	8.5.2	The A>P contrast . . . . .	265
	8.5.3	P-, IO-, and OBL-relatives . . . . .	267
8.6		Eliminating the relative clause hierarchy . . . . .	268
8.7		Discussion . . . . .	270
<b>9</b>	<b>Conclusions</b>		<b>273</b>
9.1		Key findings . . . . .	273
	9.1.1	Learning as transduction . . . . .	273
	9.1.2	Generalization with semantic similarities . . . . .	274
	9.1.3	Differential processing due to input factors . . . . .	275
9.2		Future directions . . . . .	276
	9.2.1	Perspective taking . . . . .	276
	9.2.2	Cross-linguistic study . . . . .	278
	9.2.3	Dynamic message . . . . .	280
<b>A</b>	<b>Dual-path model details</b>		<b>283</b>
A.1		Model specification . . . . .	283
A.2		Training procedure . . . . .	284
A.3		Simulation environment . . . . .	285

<b>B Improved question learning</b>	<b>287</b>
B.1 New data . . . . .	287
B.2 Analysis . . . . .	287
<b>List of Abbreviations</b>	<b>289</b>
<b>Bibliography</b>	<b>291</b>
<b>Samenvatting</b>	<b>313</b>