

# Processing hierarchical structure with RNNs

Dieuwke Hupkes

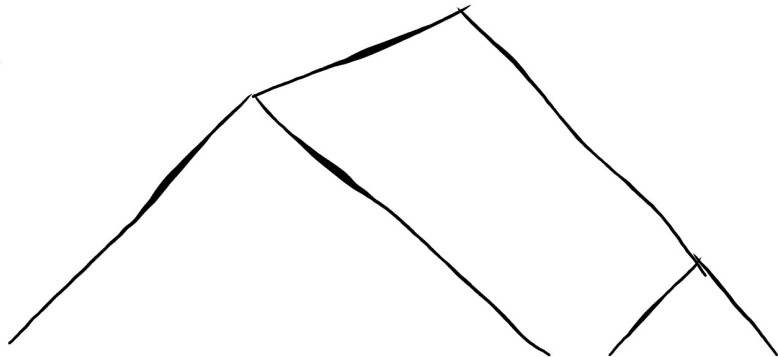
Institute for Logic, Language and Computation  
University of Amsterdam

May 9, 2017

## Hierarchical compositionality

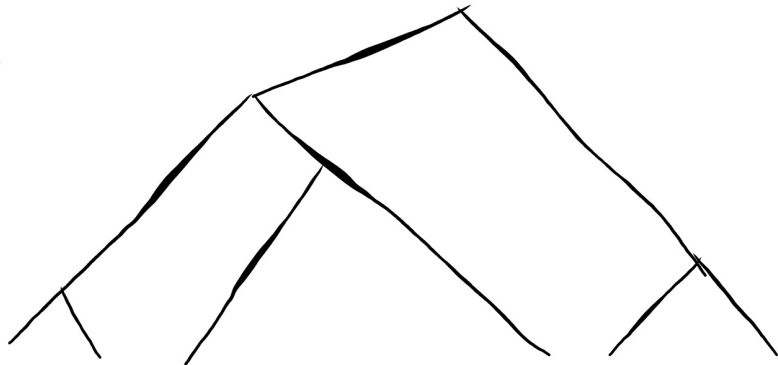
The scientist who wrote the research paper jumped with joy

## Hierarchical compositionality



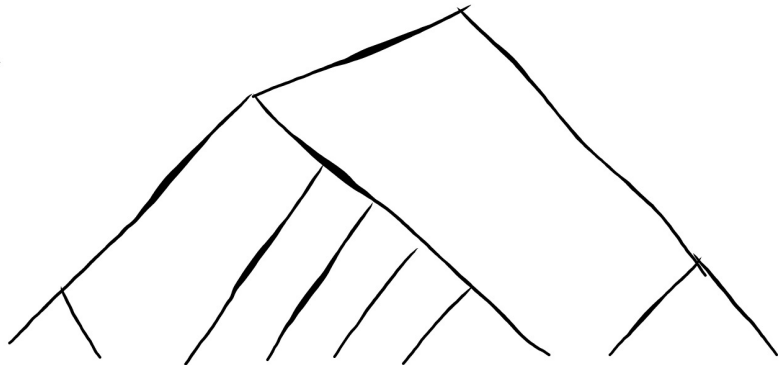
The scientist who wrote the research paper jumped with joy

## Hierarchical compositionality



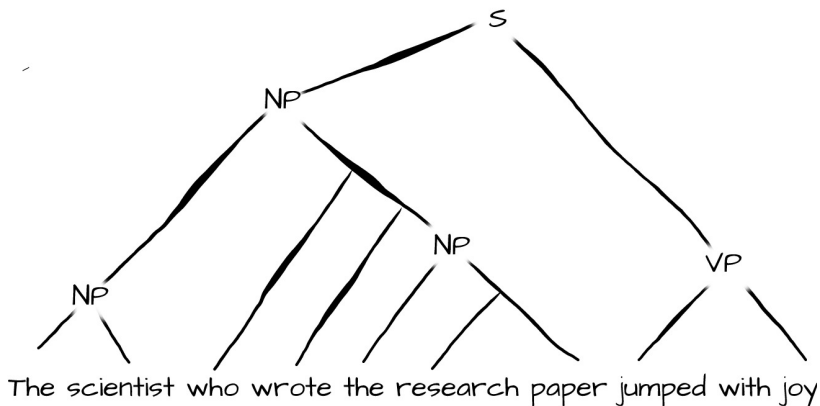
The scientist who wrote the research paper jumped with joy

## Hierarchical compositionality



The scientist who wrote the research paper jumped with joy

## Hierarchical compositionality

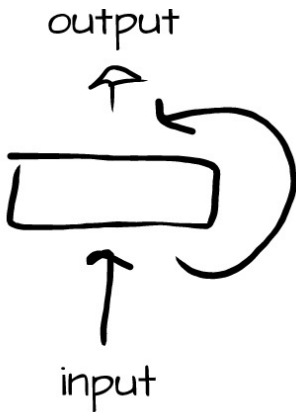


# Recurrent Neural Networks

How can hierarchical compositionality be processed incrementally, in linear time, by a recurrent artificial neural network?

## Recurrent Neural Networks

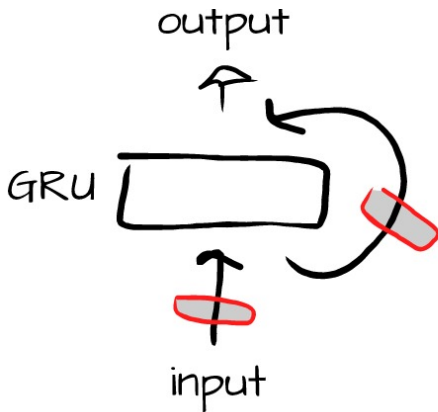
How can hierarchical compositionality be processed incrementally, in linear time, by a recurrent artificial neural network?





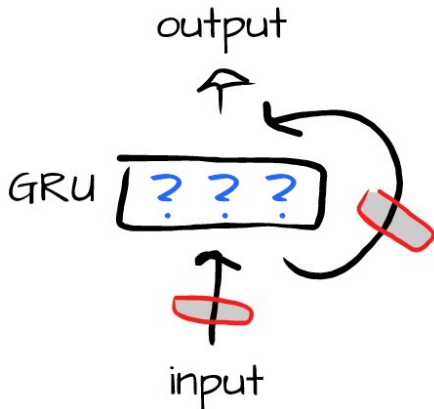
## Recurrent Neural Networks

How can hierarchical compositionality be processed incrementally, in linear time, by a recurrent artificial neural network?



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How can hierarchical compositionality be processed incrementally, in linear time, by a recurrent artificial neural network?

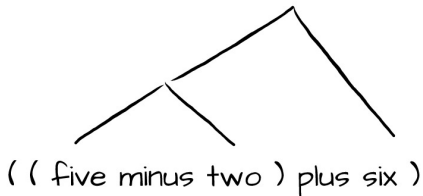
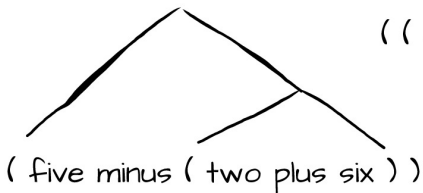


# Arithmetic Language

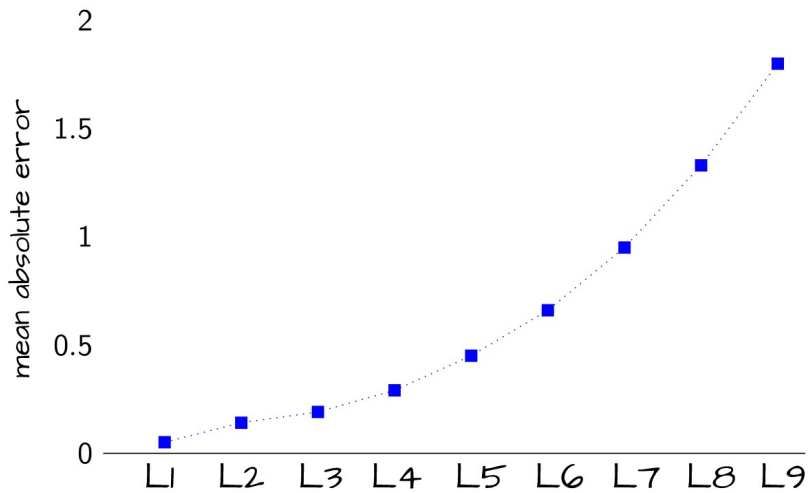
( ( five minus two ) plus six )

( five minus ( two plus six ) )

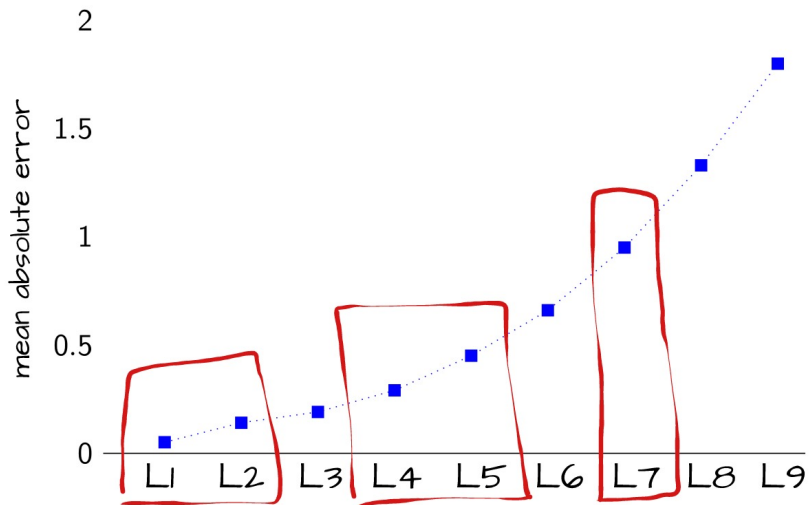
## Arithmetic Language



## Results



## Results



## Symbolic solutions

( five minus ( two plus six ) )

## Symbolic solutions

recursively

( five minus ( two plus six ) )



## Symbolic solutions

recursively

5

( five minus ( two plus six ) )

## Symbolic solutions

recursively      5      <sup>-</sup>5  
( five minus ( two plus six ) )

## Symbolic solutions

recursively



5 - 5 - 5

( five minus ( two plus six ) )

## Symbolic solutions

recursively

5   -   5   2

5, -

( five minus ( two plus six ) )

## Symbolic solutions

recursively

$$5 - (5 - (2 + 2))$$

( five minus ( two plus six ) )

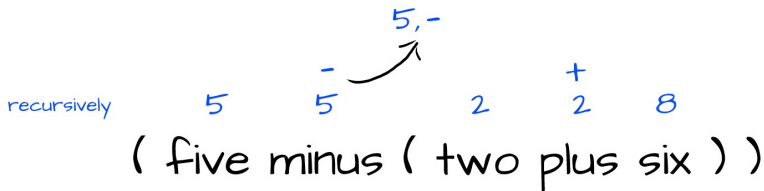
## Symbolic solutions

recursively

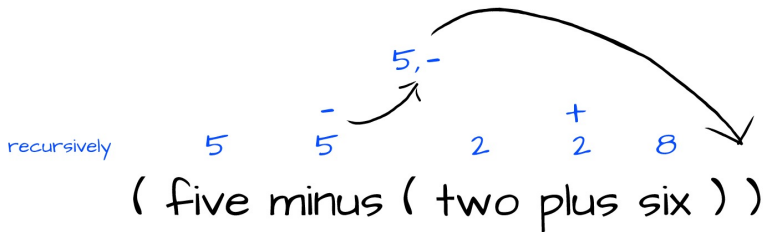
$$5 \quad - \quad 5 \quad 2 \quad + \quad 2 \quad 8$$

5, -

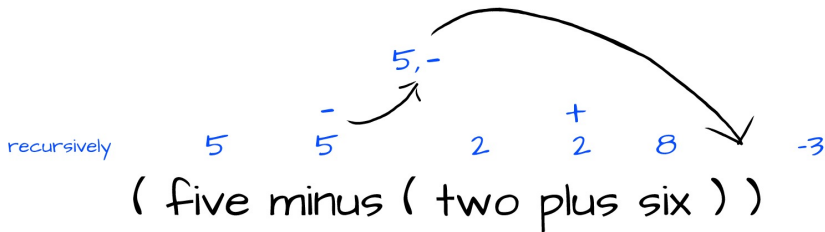
( five minus ( two plus six ) )



## Symbolic solutions

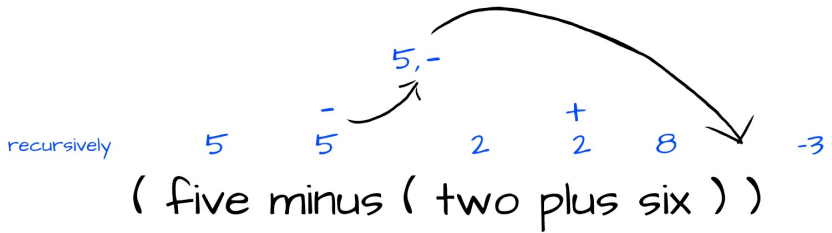


## Symbolic solutions



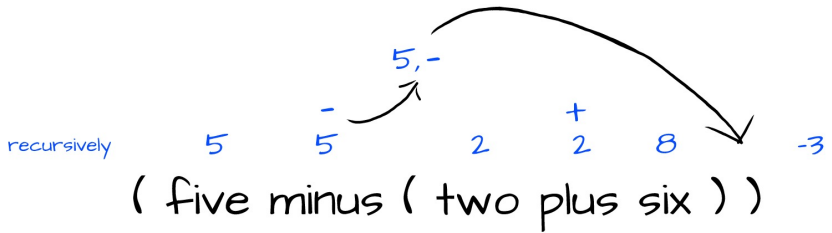


## Symbolic solutions



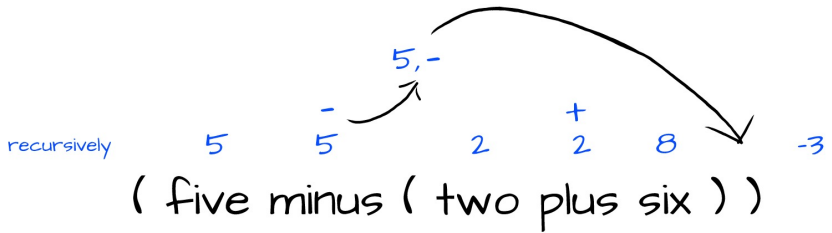
cummulatively

## Symbolic solutions



cummulatively   5

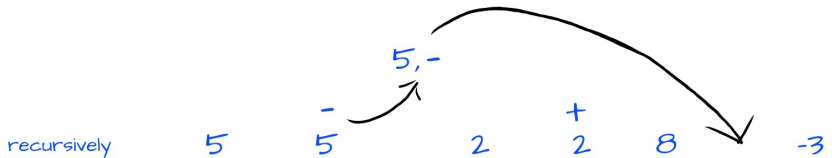
## Symbolic solutions



cummulatively

5   5   -

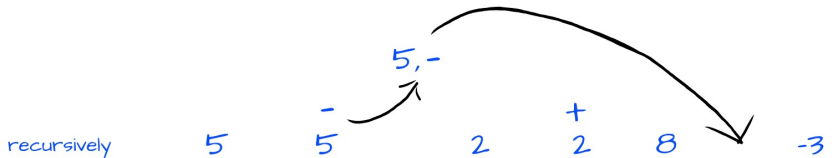
## Symbolic solutions



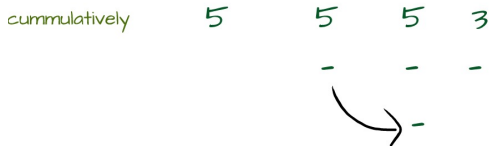
( five minus ( two plus six ) )



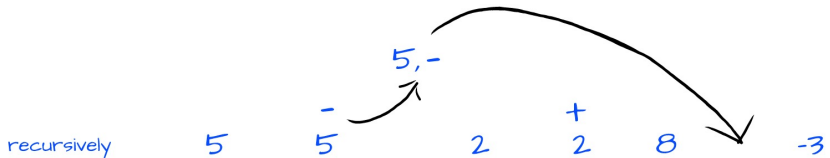
## Symbolic solutions



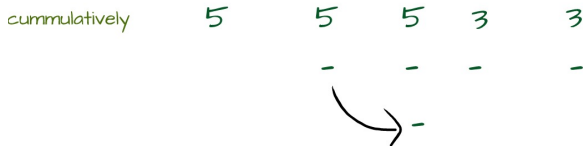
( five minus ( two plus six ) )



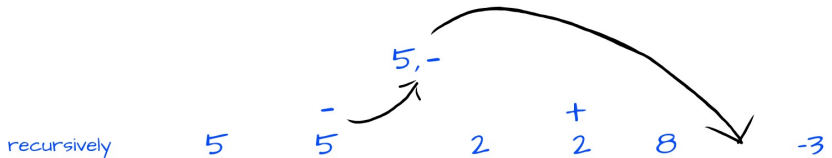
## Symbolic solutions



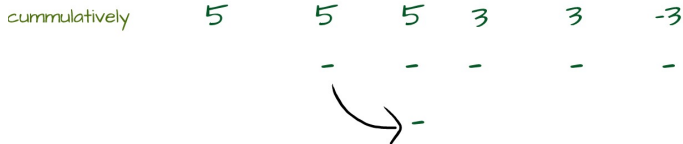
( five minus ( two plus six ) )



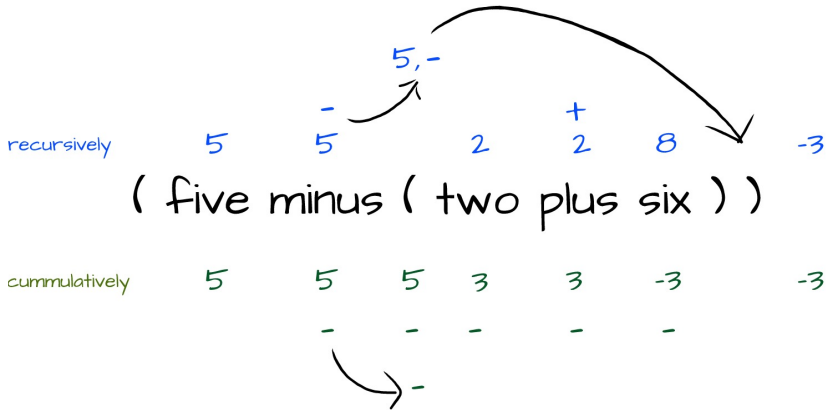
## Symbolic solutions



( five minus ( two plus six ) )

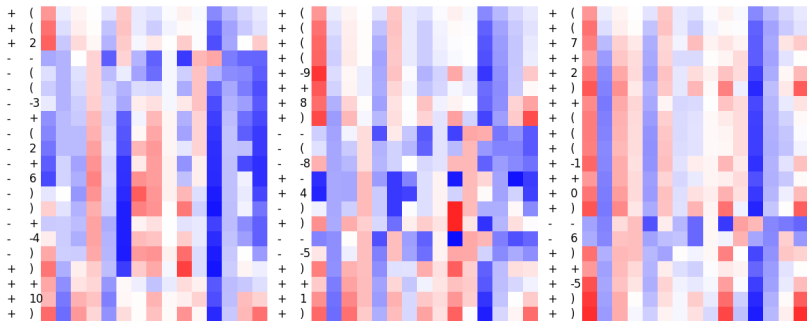


## Symbolic solutions



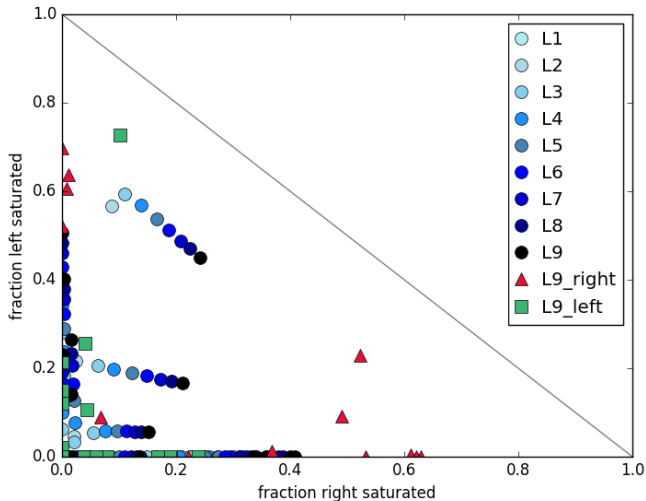


# Plotting activation values

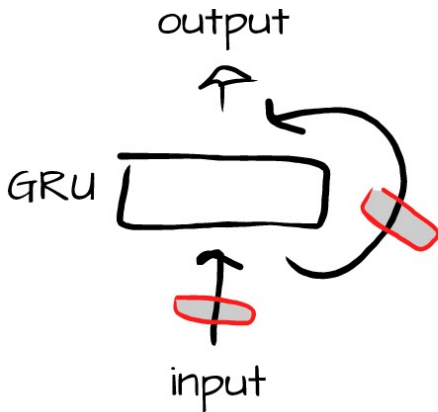


# Looking at gate statistics

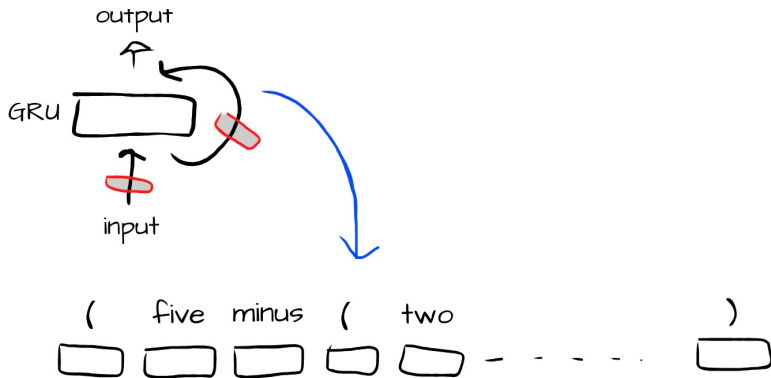
Update gate



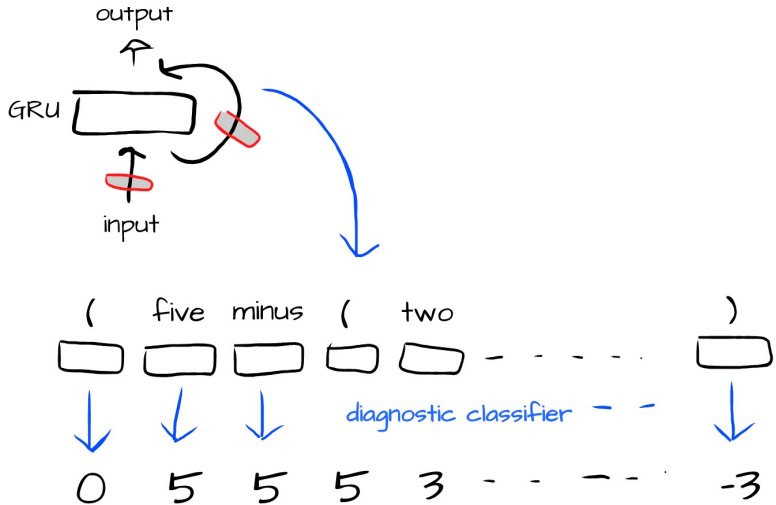
## Diagnostic Classifier



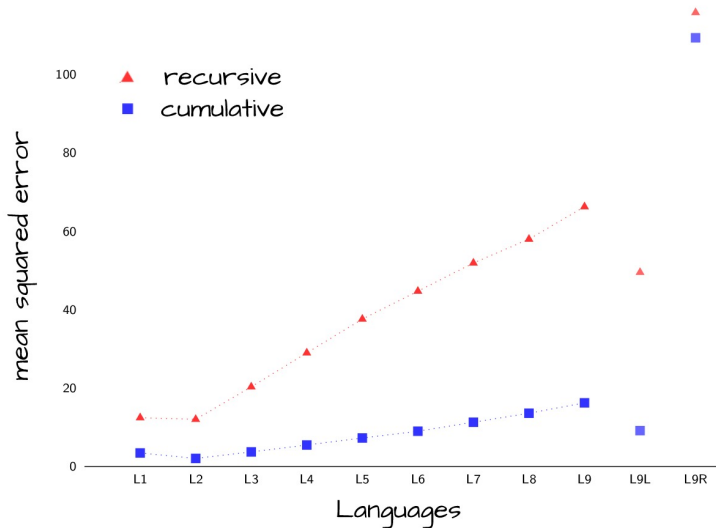
# Diagnostic Classifier



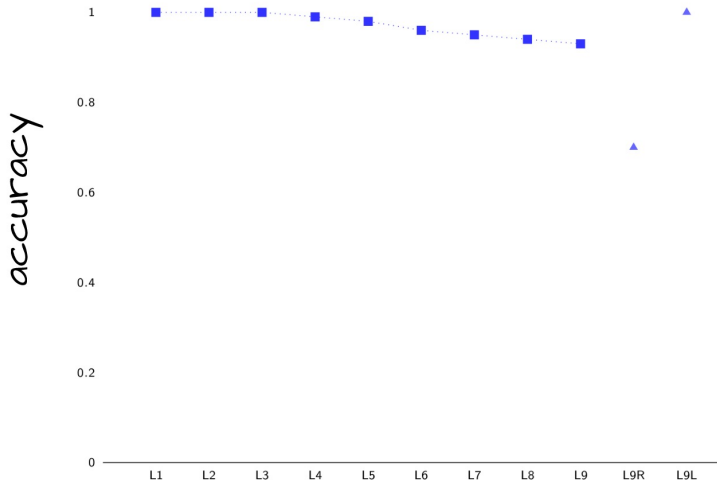
# Diagnostic Classifier



## Intermediate results



## Cumulative strategy, operation mode







## Conclusion

How do (gated) recurrent neural networks process hierarchical compositionality?

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## Conclusion

How do (gated) recurrent neural networks process hierarchical compositionality?

- diagnostic classifiers for a better understanding of RNNs
- hypotheses about language processing in the brain

