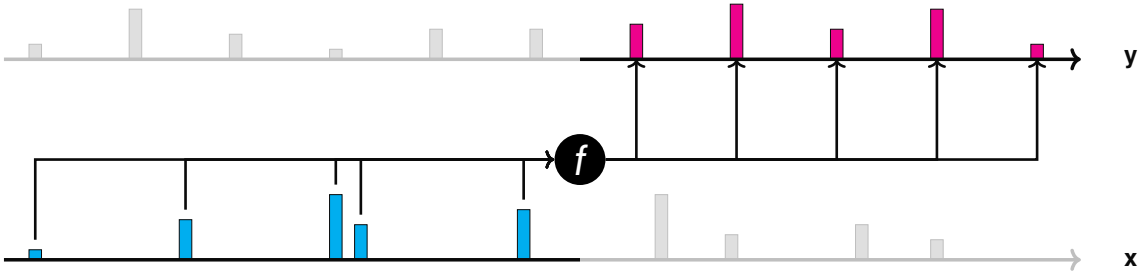
CDRNN: Discovering Complex Dynamics in Human Language Processing

Cory Shain, Ohio State (now MIT)

ACL 2021


y
f
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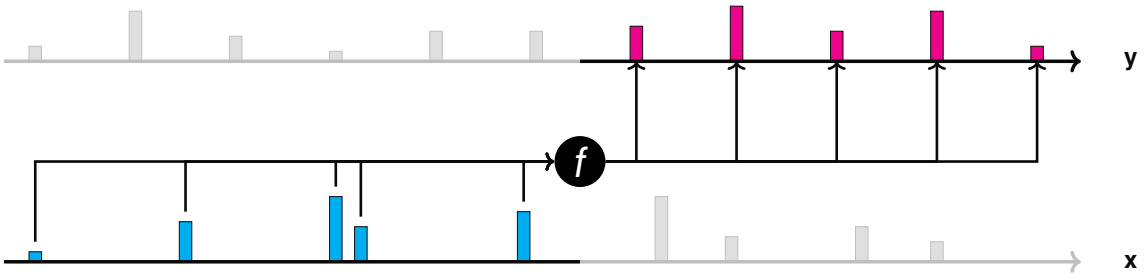
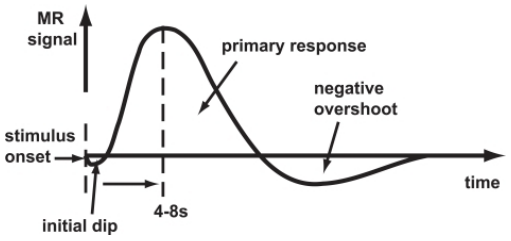
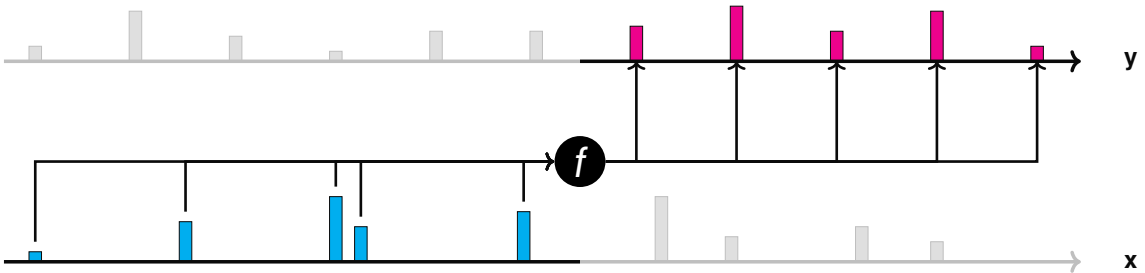
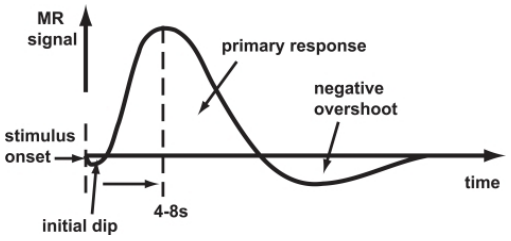
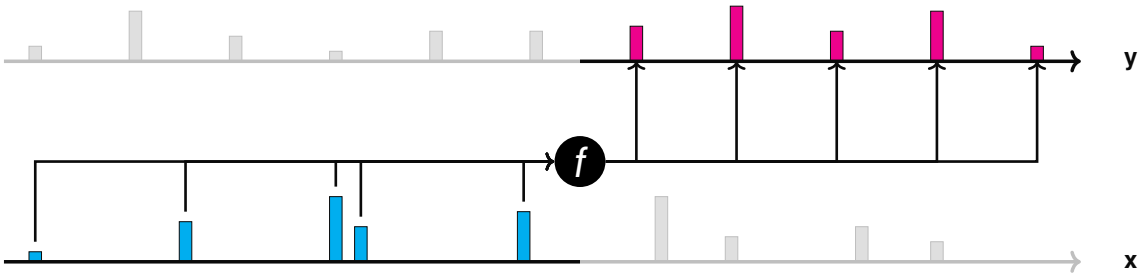

y
f
x

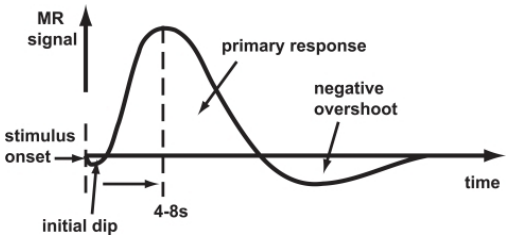

MR
signal
primary response
negative
overshoot
stimulus
onset
time
4-8s
initial dip





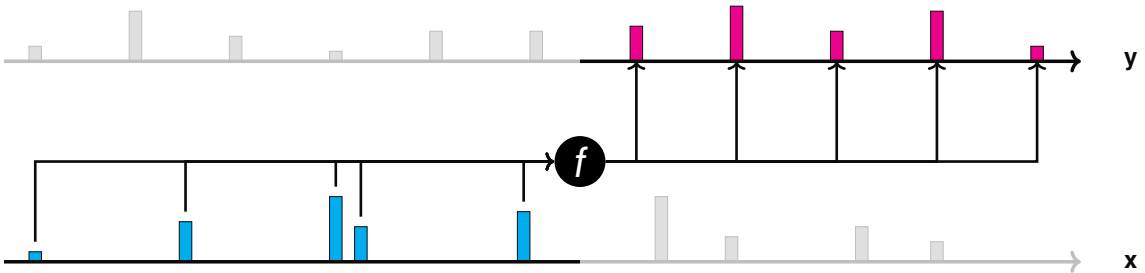
Time-Invariant

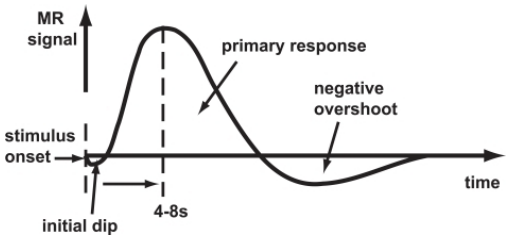




Time-Invariant

Context-Independent

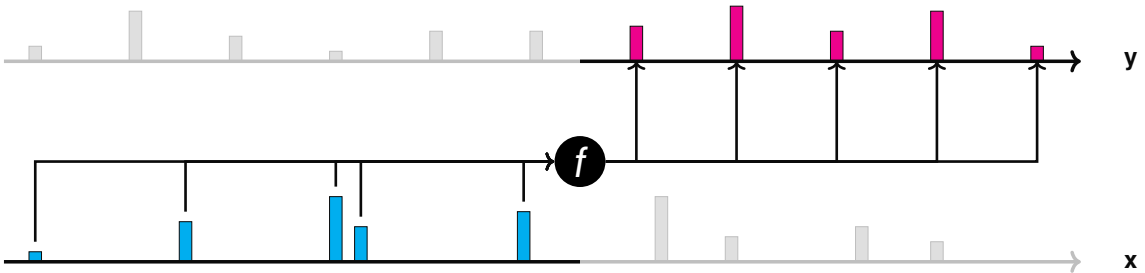


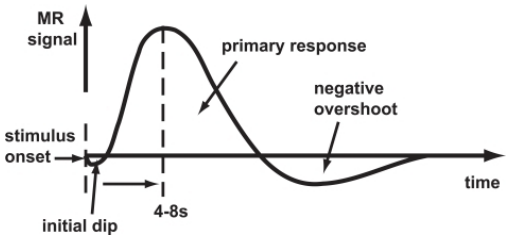


Time-Invariant

Context-Independent

Additive



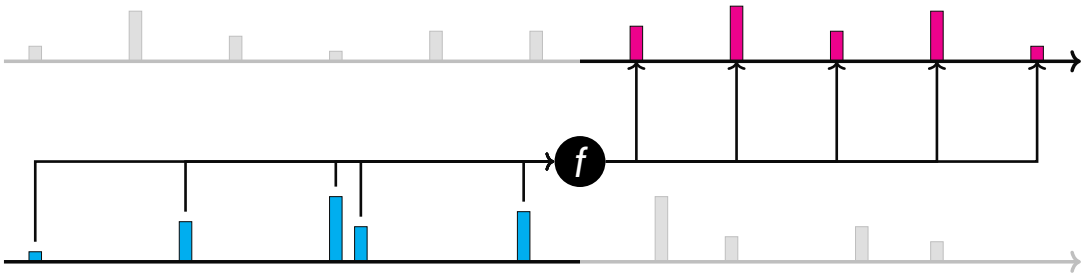


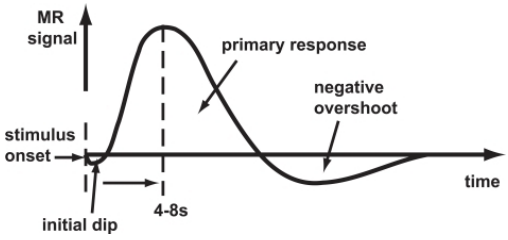
Time-Invariant

Context-Independent

Additive

Linear





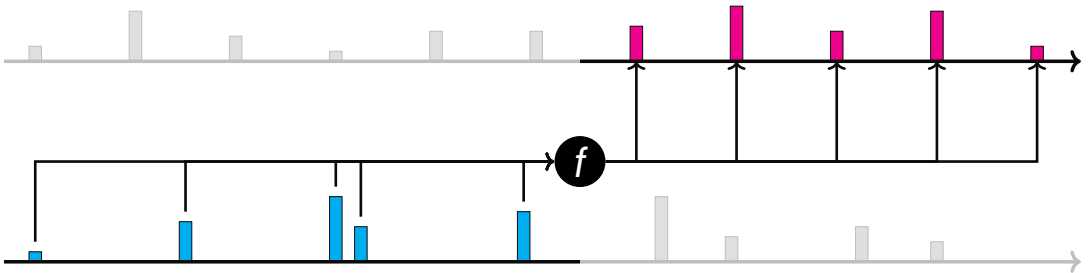
Time-Invariant

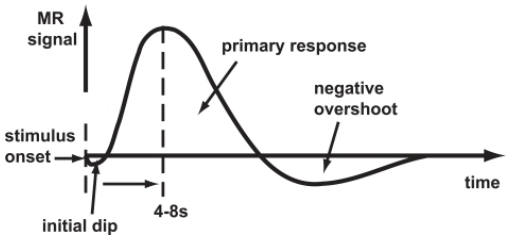
Context-Independent

Additive

Linear

Constant Uncertainty





Time-Invariant

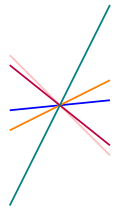
Context-Independent

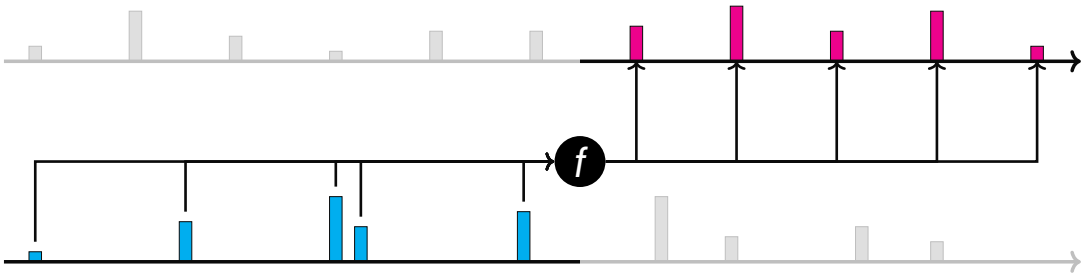
Additive

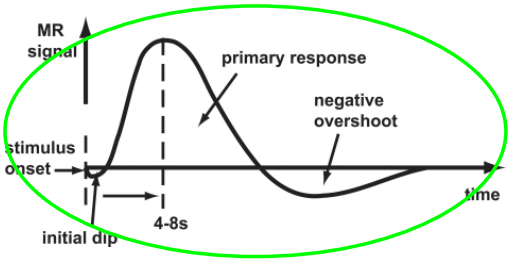
Linear

Constant Uncertainty

$\longrightarrow f =$







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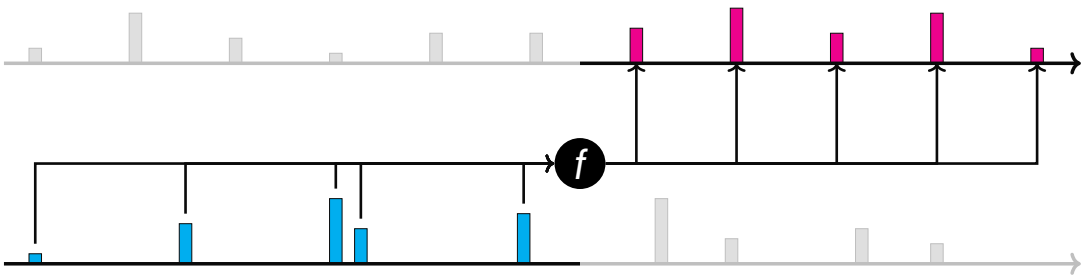

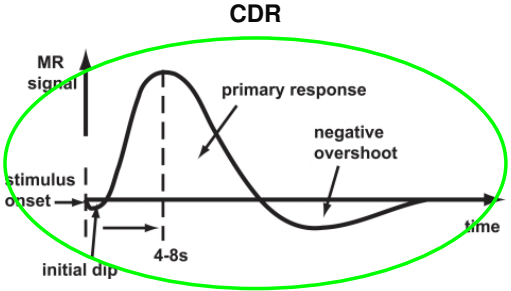

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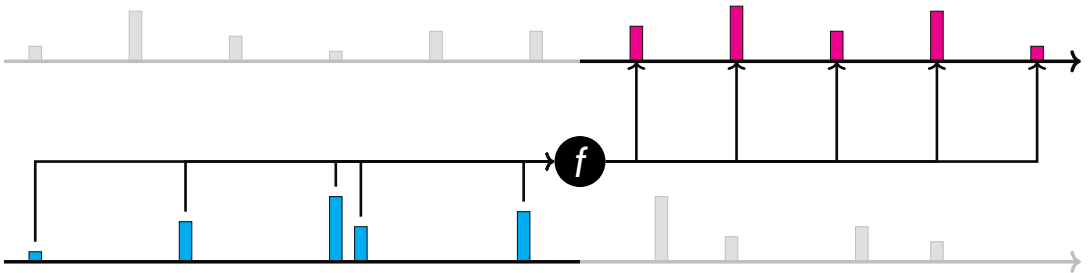

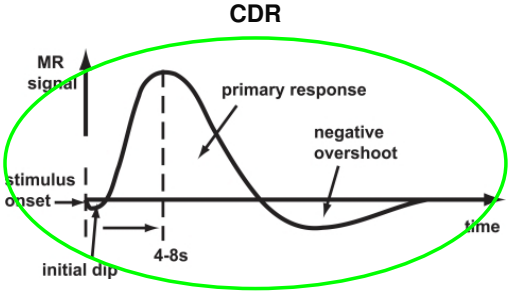

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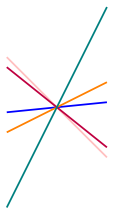
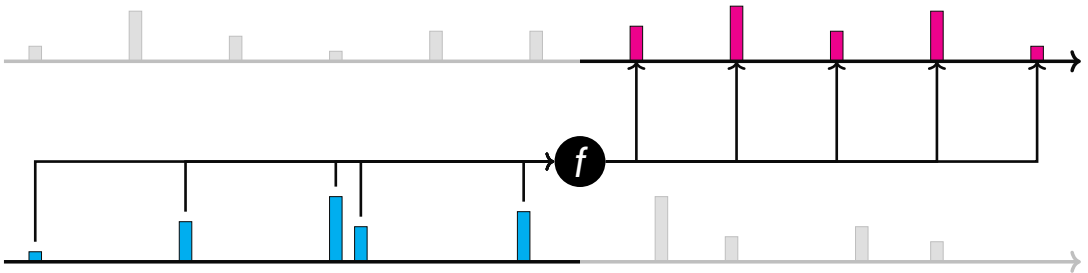
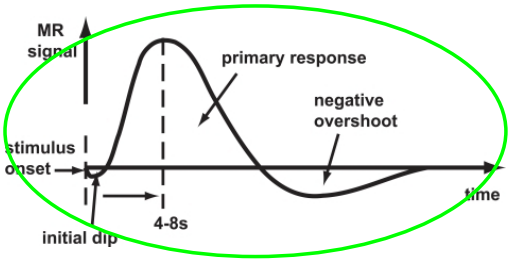
$\longrightarrow f =$





CDR



CDRNN

Time-Invariant

Context-Independent

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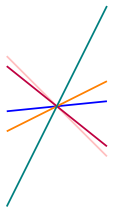
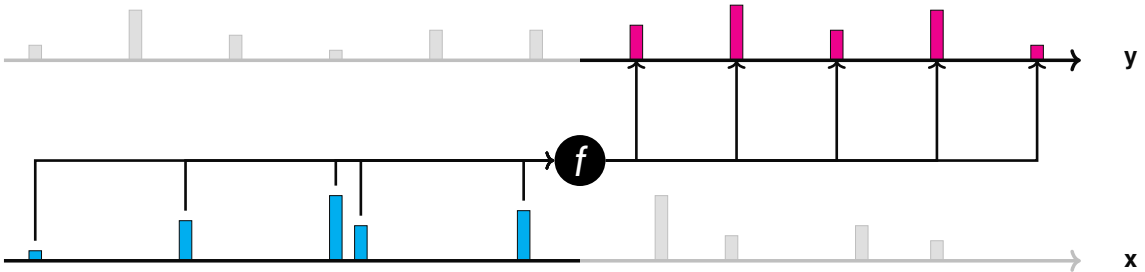
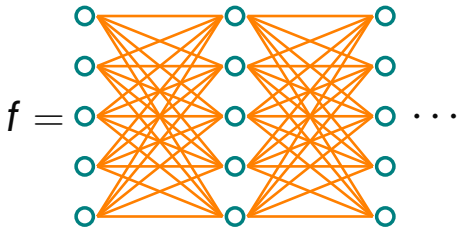
Linear

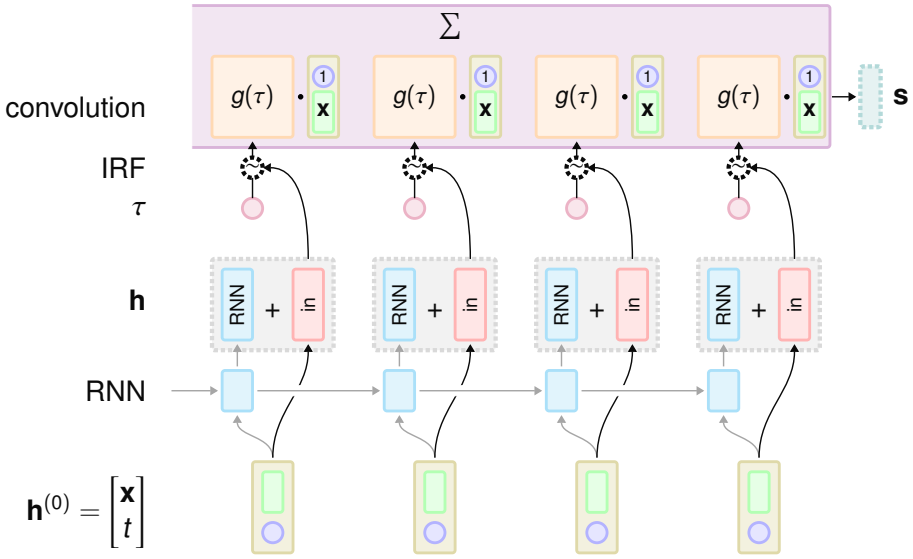
Constant Uncertainty

$\longrightarrow f =$




y
f
x

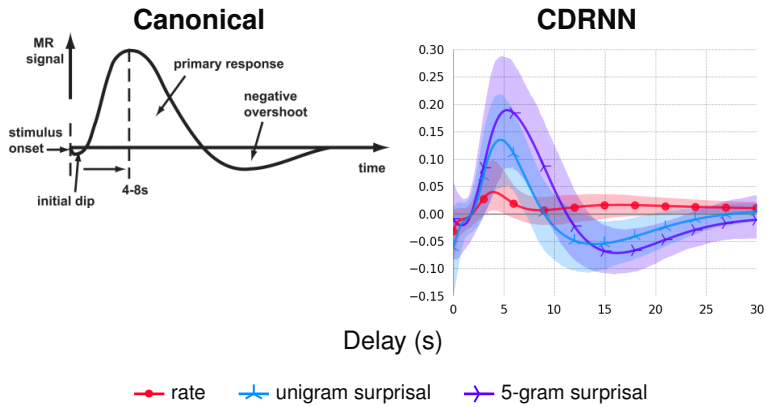

f =
· · ·

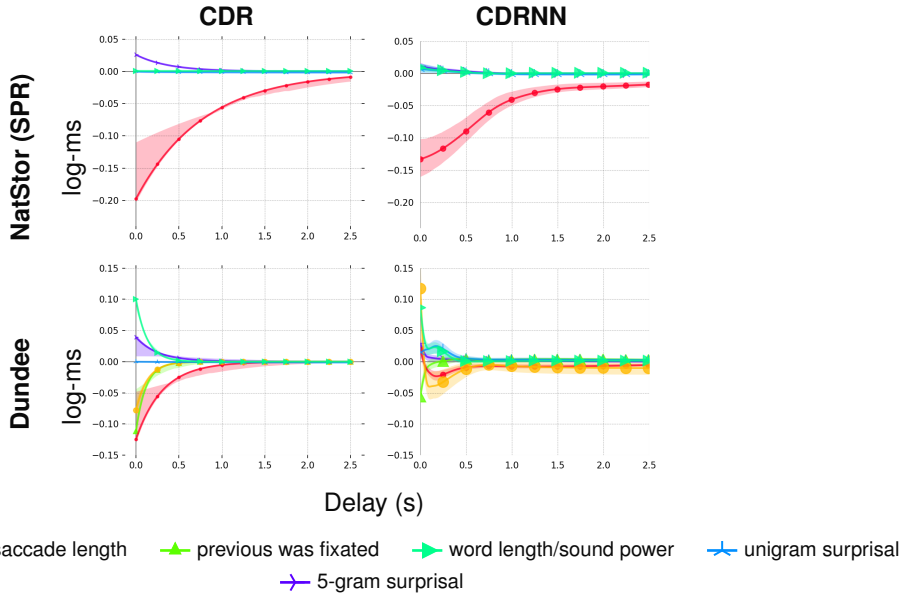

convolution
IRF
τ
h
RNN
$\mathbf{h}^{(0)} = \begin{bmatrix} \mathbf{x} \\ t \end{bmatrix}$
Σ
$g(\tau)$
1
x
s
RNN
+
in

		CDRNN	
		Feedforward	RNN
Baseline	Modality	*p*	*p*
LME	Reading	**0.0001*****	**0.0001*****
GAM	Reading	**0.0001*****	**0.0001*****
Canonical HRF	fMRI	**0.0001*****	**0.0001*****
Interpolated	fMRI	**0.0001*****	**0.0001*****
Averaged	fMRI	**0.0001*****	**0.0001*****
Lanczos	fMRI	**0.0001*****	**0.0001*****
CDR	Both	**0.0001*****	**0.0001*****

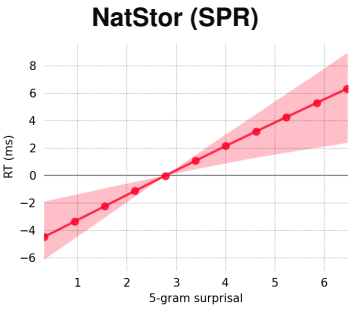
Model validation

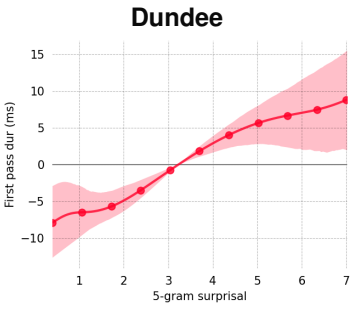
Significance of test-set error improvement
(eye-tracking, self-paced reading, and fMRI)

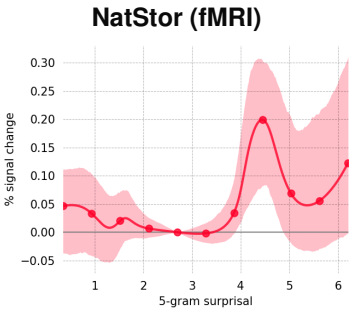

Canonical
MR signal
primary response
negative overshoot
stimulus onset
time
4-8s
initial dip
CDRNN
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
0
5
10
15
20
25
30
Delay (s)
rate
unigram surprisal
5-gram surprisal


CDR
CDRNN
NatStor (SPR)
Dundee
log-ms
log-ms
Delay (s)
rate
saccade length
previous was fixated
word length/sound power
unigram surprisal
5-gram surprisal

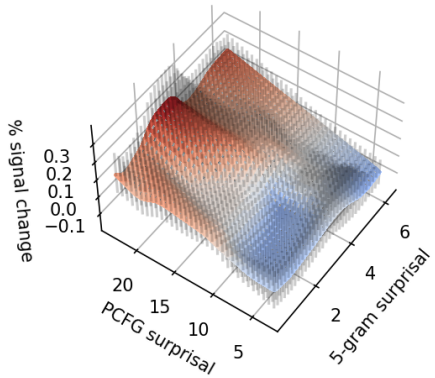
Instantaneous



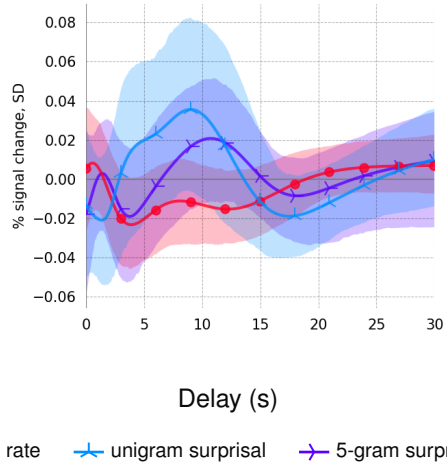




Linearity of surprisal effects



Interaction between PCFG and 5-gram surprisal at peak fMRI response



Stimulus-driven change in response **spread** (fMRI)

CDRNN leverages deep learning to provide powerful and flexible new analytics for psycholinguistics and cognitive (neuro)science

Thank you!

Code: https://github.com/coryshain/cdr

Data: https://osf.io/eyp8q/