The unified model for single-word processing

Main Goal:

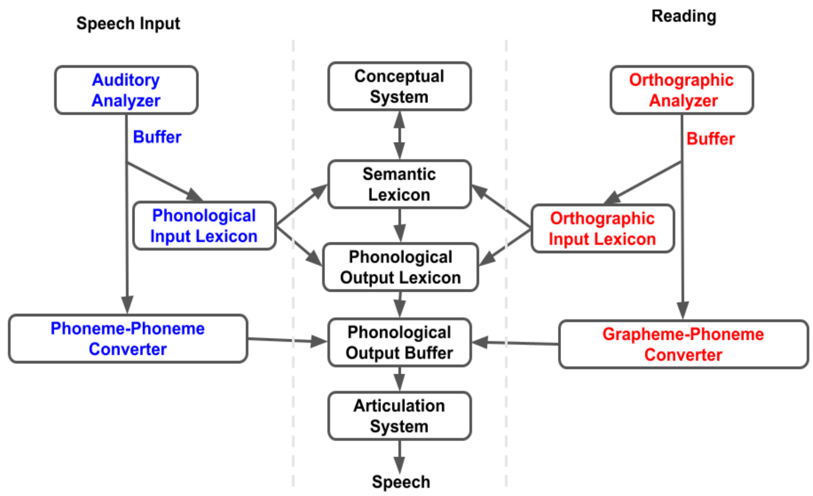
Create a global map of the processing pathways in the brain for single-word processing and identify its amodal parts. The ultimate goal of the project is to provide a global view of single-word processing in the brain, delineating the various processing stages and, in particular, disentangling modality-specific and amodal processing of words. We will test the hypothesis that the unified single-word processing model (Dotan et al., 2015) can be mapped onto the human language network, such that each processing component (boxes and arrows in the model) can be mapped onto dedicated brain regions.

Background:

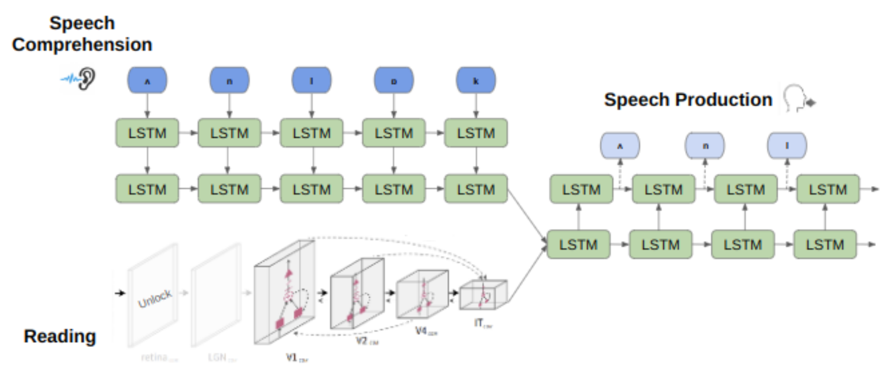
The human brain can process single words during different tasks and via different modalities. We can hear the word `apple' and repeat it out loud, or we see the word written on a page and read it, or we think of its concept, or see an image of it and name it out loud. These three tasks (word repetition, reading and naming) require different computations at early stages, but share others at higher, amodal, levels, as described by the unified model for single-word processing (Dotan & Friedmann, 2015). Decades of research in neuropsychology and cognitive sciences have produced a detailed description of the various information-processing stages during each of these tasks, based on examination of patients with brain damage, often highly localized. Each of these processing steps is considered a separate module, which can be selectively impaired following a focal brain lesion, which would lead to specific error patterns in one or more of these tasks. For instance, patients, who were skilled readers in the past, after a stroke, can show reading errors that have a specific pattern, such as reading `move' as `mauve', or `none' as `known', however, with no difficulties with regular words such as `man' or `hear'. This pattern can be explained by a deficit in accessing lexical information, which becomes most apparent for such irregular words (as ‘move’), since these words are read based on grapheme-to-phoneme conversion rules (right-most route in the unified model). Other patients show error patterns such as reading `broad' as `board', `loin' as `lion' or `beard' as `bread'. This pattern suggests a selective impairment in letter-position processing, at early processing in the orthographic-visual analysis system (top-right component of the model). Similarly, if there's a deficit in the semantic lexicon (top of middle route), it can lead to anomia, where semantic paraphasias occur, replacing a word with one that is semantically related (e.g., substituting `lion' with `tiger').

Dotan, D., & Friedmann, N. (2015). Steps towards understanding the phonological output buffer and its role in the production of numbers, morphemes, and function words. Cortex, 63, 317-351.

Friedmann, N., & Coltheart, M. (2018). 35. Types of developmental dyslexia. Handbook of communication disorders: Theoretical, empirical, and applied linguistic perspectives, 721-752.



<u>Implementing the Cognitive model with Deep Neural Networks:</u>



<u>Architecture:</u>

Auditory pathway:

- Sequence processing: start with RNNs, trained on a sequence of phones.
- Word repetition: for both comprehension and production.

Visual pathway:

- CNNs. Explore with standard CNNs, as in AlexNet, first trained on images of objects then refined on letter strings (see Hannagan et al., 2021).
- Test with [CORnet]

Hannagan, T., Agrawal, A., Cohen, L., & Dehaene, A. S. (2021). Emergence of a compositional neural code for written words: Recycling of a convolutional neural network for reading. Proceedings of the National Academy of Sciences, 118(46), e2104779118.

Agrawal, A., & Dehaene, S. (2024). Cracking the neural code for word recognition in convolutional neural networks. arXiv preprint arXiv:2403.06159.

Agrawal, A., & Dehaene, S. (2023). Dissecting the neuronal mechanisms of invariant word recognition. bioRxiv, 2023-11.

Kubilius, J., Schrimpf, M., Nayebi, A., Bear, D., Yamins, D.L.K., DiCarlo, J.J. (2018) CORnet: Modeling the Neural Mechanisms of Core Object Recognition. biorxiv. doi:10.1101/408385

Kubilius, J., Schrimpf, M., Kar, K., Rajalingham, R., Hong, H., Majaj, N., ... & Dicarlo, J. (2019). Brain-like object recognition with high-performing shallow recurrent ANNs. In Advances in Neural Information Processing Systems (pp. 12785-12796).

Burgess, N., & Hitch, G. J. (1992). Toward a network model of the articulatory loop. Journal of memory and language, 31(4), 429-460.

Botvinick, M. M., & Plaut, D. C. (2006). Short-term memory for serial order: a recurrent neural network model. Psychological review, 113(2), 201.

Sajid, N., Holmes, E., Costa, L. D., Price, C., & Friston, K. (2022). A mixed generative model of auditory word repetition. bioRxiv, 2022-01.

Tasks:

- Train the model and run sanity checks (convergence, etc.)
- Prepare a grid-search to optimize hyper-parameters (number of units in latent layers, etc).
- Literature review

Datasets:

Training:

- For RNNs: Create a corpus with 50K words, including morphologically complex words.
- For each word have the phonological transcription (if needed, look for phonetic databases, text-to-speech TTS tools, etc).

Evaluation:

- Cross validation on left-out words from the lexicon.
- Factorial Design: Sarah's list of words based on the factorial design (see figure below). Convert to a list of.
    - **Pseudowords**: Create a list of Pseudowords. Use Pallier's pseudoword generator, unipseudo, reachable from openlexicon.fr. Convert to strings of phones and images with written words.
    - **Real words:** Convert to strings of phones and images with written words.
- Links to Sarah's stimuli: English French
- Deliane's: https://github.com/dbechar/Morphemes-Behavioral-Experiment/tree/main/experimental_design

Code:

- Keep in mind that, in the future, we may add working-memory mechanisms into units of the model.

Misc Libraries Consulted: https://github.com/dbechar/Morphemes-Behavioral-Experiment/tree/main

Condition	Modality	Lexicality	Length	Morph Complexity	Frequency	Example
1	V	R	S	S	L	pond
2	V	R	S	S	H	hand
3	V	R	S	C	L	jigs
4	V	R	S	C	H	dogs
5	V	R	L	S	L	umbrella
6	V	R	L	S	H	mountain
7	V	R	L	C	L	giraffes
8	V	R	L	C	H	bedrooms
9	V	P	S	S	-	pold
10	V	P	S	C	-	nars
11	V	P	L	S	-	blondrel
12	V	P	L	C	-	snorkfles
13	A	R	S	S	L	pond
14	A	R	S	S	H	hand
15	A	R	S	C	L	jigs
16	A	R	S	C	H	dogs
17	A	R	L	S	L	umbrella
18	A	R	L	S	H	mountain
19	A	R	L	C	L	giraffes
20	A	R	L	C	H	bedrooms
21	A	P	S	S	-	pold
22	A	P	S	C	-	nars
23	A	P	L	S	-	blondrel
24	A	P	L	C	-	snorkfles