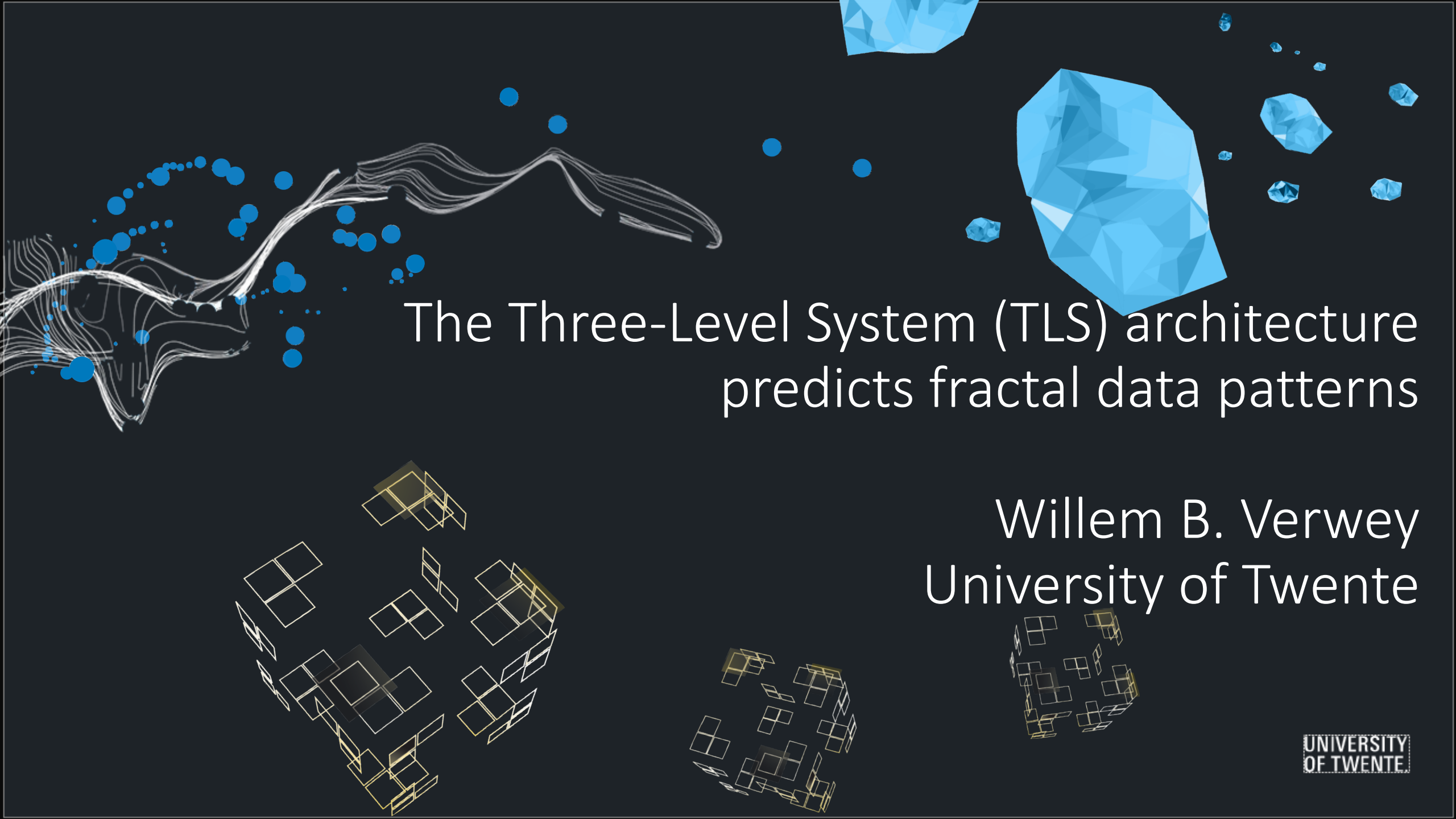

The Three-Level System (TLS) architecture predicts fractal data patterns

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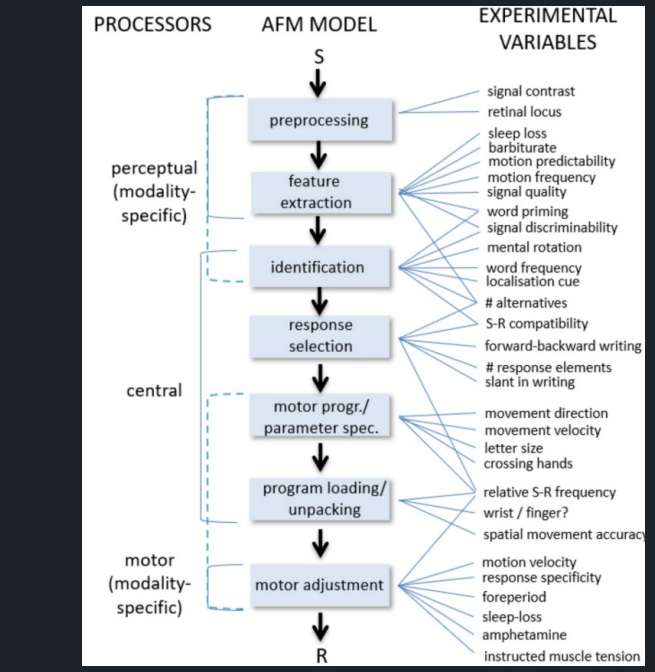
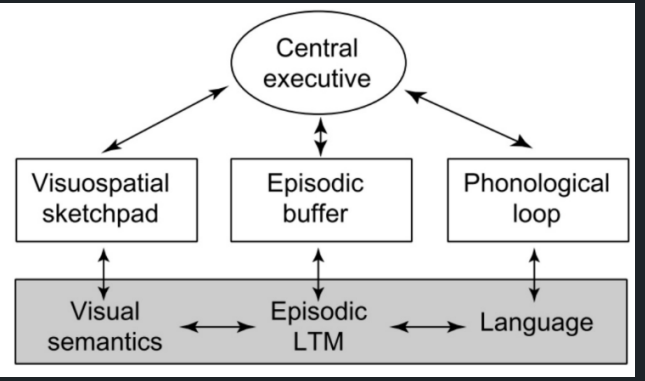
INTRODUCTION

- cognitive models assume
  - serial processes (Sternberg, 1969)
  - processing and memory are separate functions
    - LTM: declarative (semantic and episodic) and procedural (cognitive and motor skills) (Tulving, 1972)
    - STM: temporary memory, up to about 4 items (Baddeley & Hitch, 1974; Cowan, 2000)
  - how can this be based in a massively parallel working brain!?





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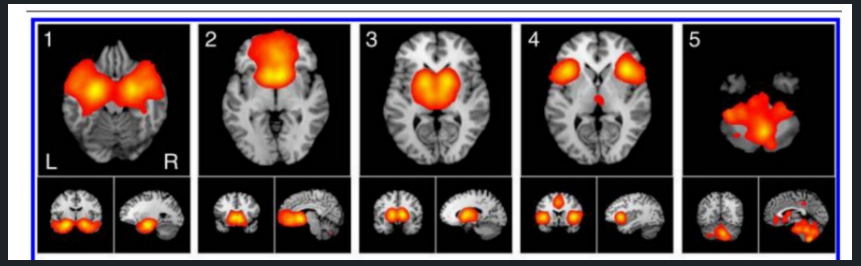
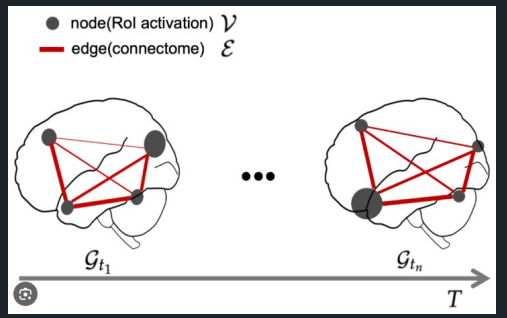
MEMORY AND PROCESSING - IN THE BRAIN



- various neural models: a.o. activation models (fMRI), network models (EEG, graph theory)



- neural models assume
  - active representations are somehow based in oscillatory patterns across a network of cortical areas
  - STM: cortical areas seem temporarily connected by the
    - prefrontal cortex
    - hippocampus (declarative memory)
    - the basal ganglia/thalamus (procedural network)
  - LTM: cortical areas are permanently connected via corticocortical pathways

THE TLS ARCHITECTURE [1]

- the TLS architecture explains cognitive functions in a massively parallel brain
    - STM consists of temporary oscillatory networks also influenced by
    - LTM based in permanent corticocortical connections
    - cognitive processing stages: based on adjusting networks by the PFC or BG
        - one oscillatory pattern (i.e., process input) → another (i.e., process output)
        - like with serial motor control

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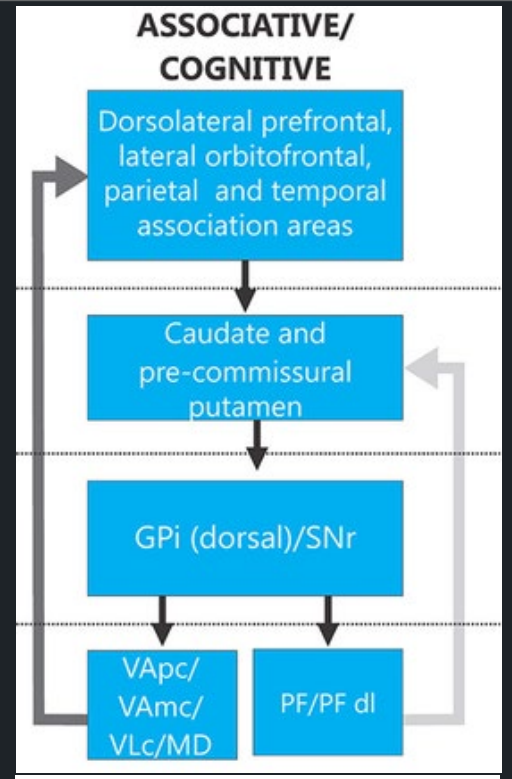
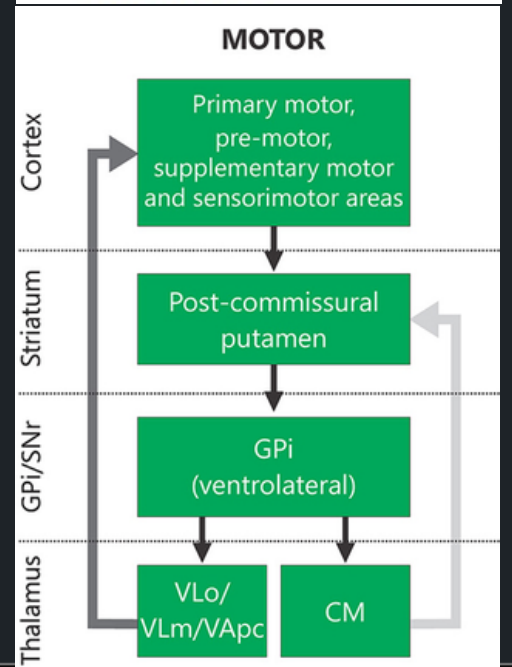
[1] *Verwey, W. B. (2025). The neural basis of cognitive processing: A review and a speculative architecture. Brain and Cognition, 189, 106351.*

THE TLS ARCHITECTURE

- control and development of serial motor skills (cf. Verwey, 2024)
  - cognitive mode: successive <u>symbolic representations</u> in association cortex triggered by the PFC (STM) = consciously controlled
    → associative/cognitive cortico-subcortical loop
  - associative mode: successive <u>motor representations</u> in motor cortex triggered by the basal ganglia = familiar movement series
    → (sensori-)motor cortico-subcortical loop
  - autonomous (automatic) mode: successive motor representations integrated in motor cortex = habit
    → triggered by preSMA/SMA (via intracortical connections; no loop)
- so, with practice control shifts to a 'lower' level

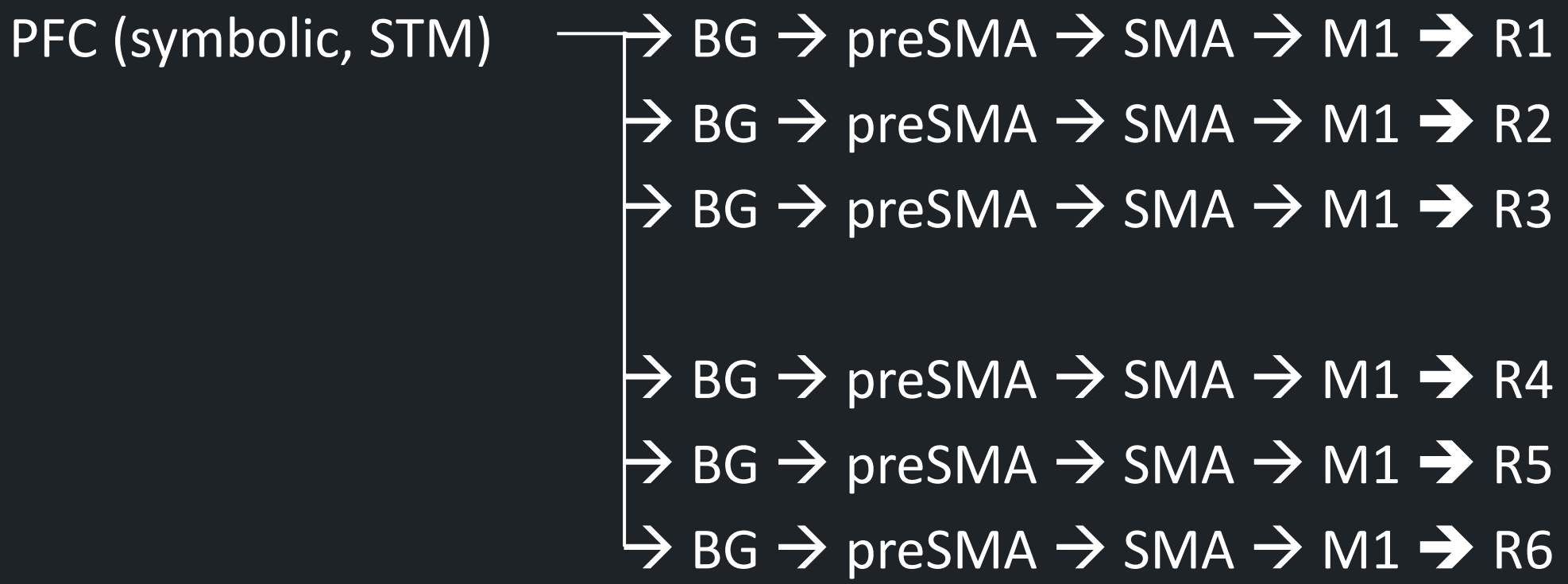




Verwey, W. B. (2024). C-SMB 2.0: Integrating over 25 years of motor sequencing research with the Discrete Sequence Production task. Psychonomic Bulletin & Review, 31, 931–978.

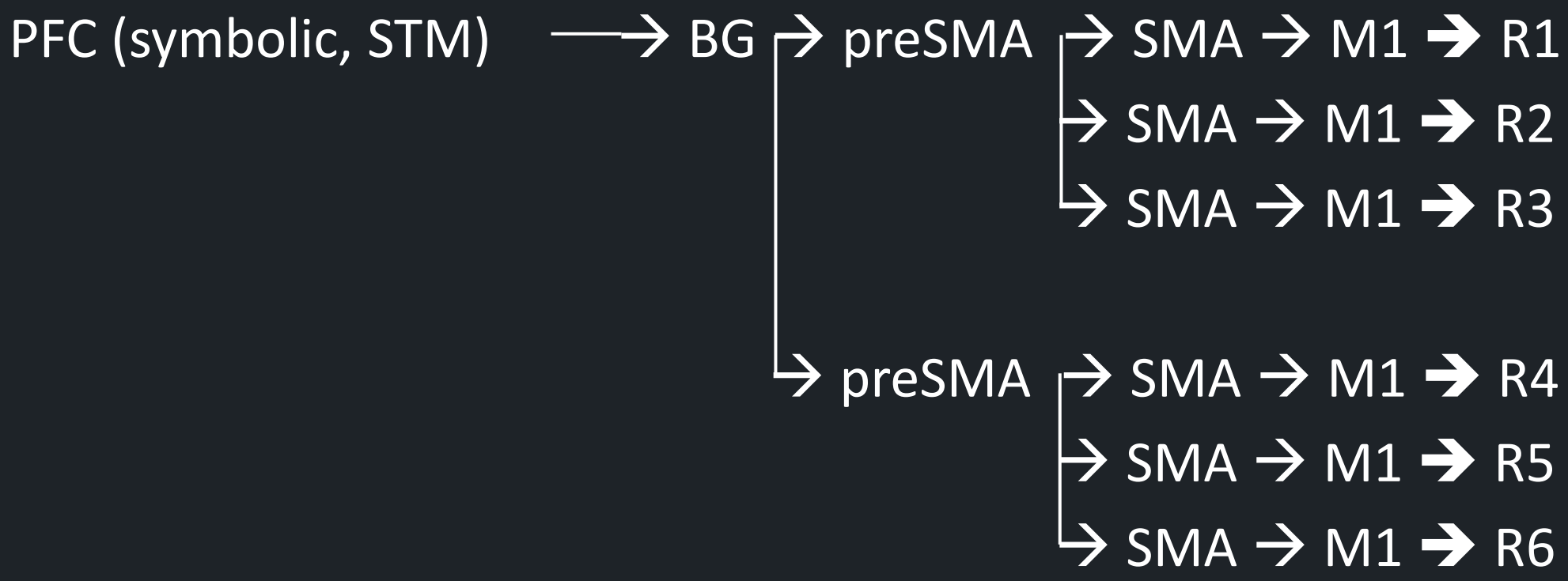
COGNITIVE MODE

PFC triggers individual (symbolic) movement representations in BG



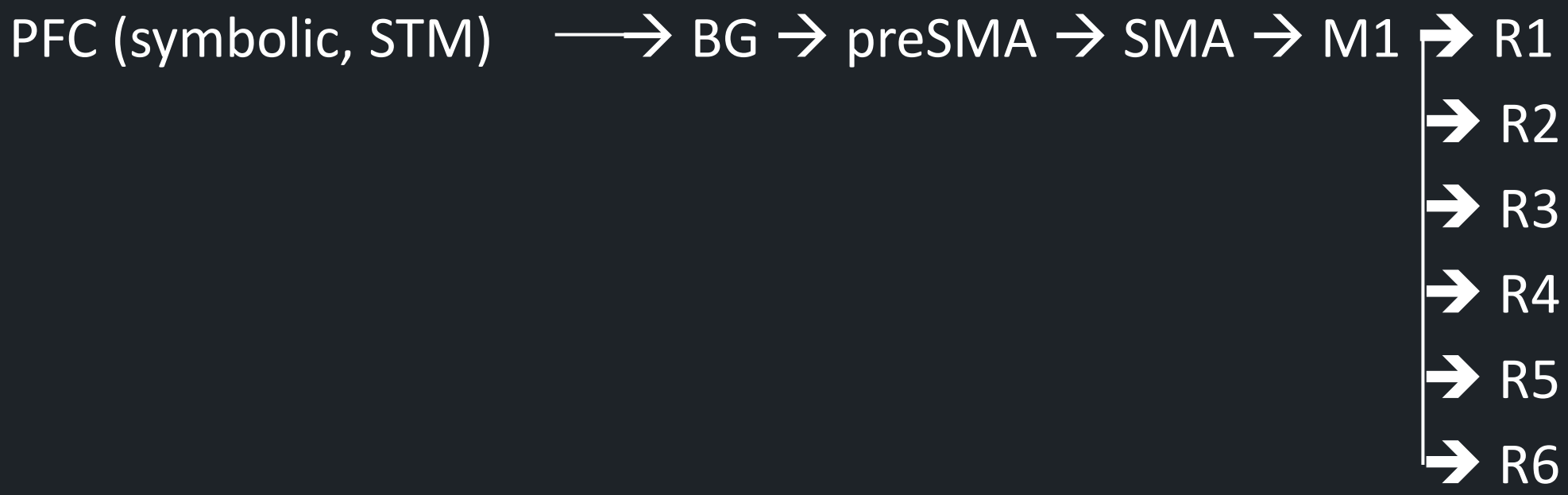
ASSOCIATIVE MODE

BG triggers short motor chunks of (3) movements in preSMA



AUTONOMOUS MODE

movement habit selected by PFC, then each movement in M1 triggers the next



SO, THE TLS ARCHITECTURE [1]

- explains hierarchical (motor) control & concurrent processing

- interference
  - Contextual Interference: Random Practice learns better than Blocked Practice
    - Random Practice: repeated preparation → memory consolidation at higher control levels
  - secondary task interference reduces with practice
    - less PFC and basal ganglia involvement

- predicts that with practice of serial motor skills
  - preparation increases : PFC tunes the neural system to the current muscle state
  - execution: reducing hierarchical control as automaticity develops
    this may be reflected in fractal behavior (Grosu et al., 2022[2])
    - reducing repetition of behavioral patterns at different time scales
    - possibly, scale-invariant dynamics - per control level

[1] *Verwey, W. B. (2025). The neural basis of cognitive processing: A review and a speculative architecture. Brain and Cognition, 189, 106351.*
[2] *Grosu, G.F. et al. (2022). The fractal brain: Scale-invariance in structure and dynamics. Cerebral Cortex, 33(8), 4574–4605*

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and now …

testing fractal behavior
in a developing serial motor skill

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CONCLUSIONS

- the TLS architecture [1] can account for
  - motor sequence control in 3 modes (cognitive, associative and autonomous)
  - at moderate skill levels: control occurs at PFC (initiation), BG (chunks), (pre)SMA, and M1 (individual movements)
  - secondary task interference, contextual interference
  - 3 simultaneous control levels suggests variability (adjustments) at, at least three levels (is not noise)

- predicted
  - motor sequence execution may exhibit fractal behavior in performance (timing, accuracy, force) [2]
    (i.e., self-similarity across time scales and, possibly, scale-invariant dynamics)
  - more preparation -> more processing during preparation *and* less processing during execution
    control at different hierarchical levels may well show fractal patterns

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[1] *Verwey, W. B. (2025). The neural basis of cognitive processing: A review and a speculative architecture. Brain and Cognition, 189, 106351.*