A Bayesian Account of Temporal Consciousness

From Event Processing to the Experience of Flow

Zafeirios Fountas

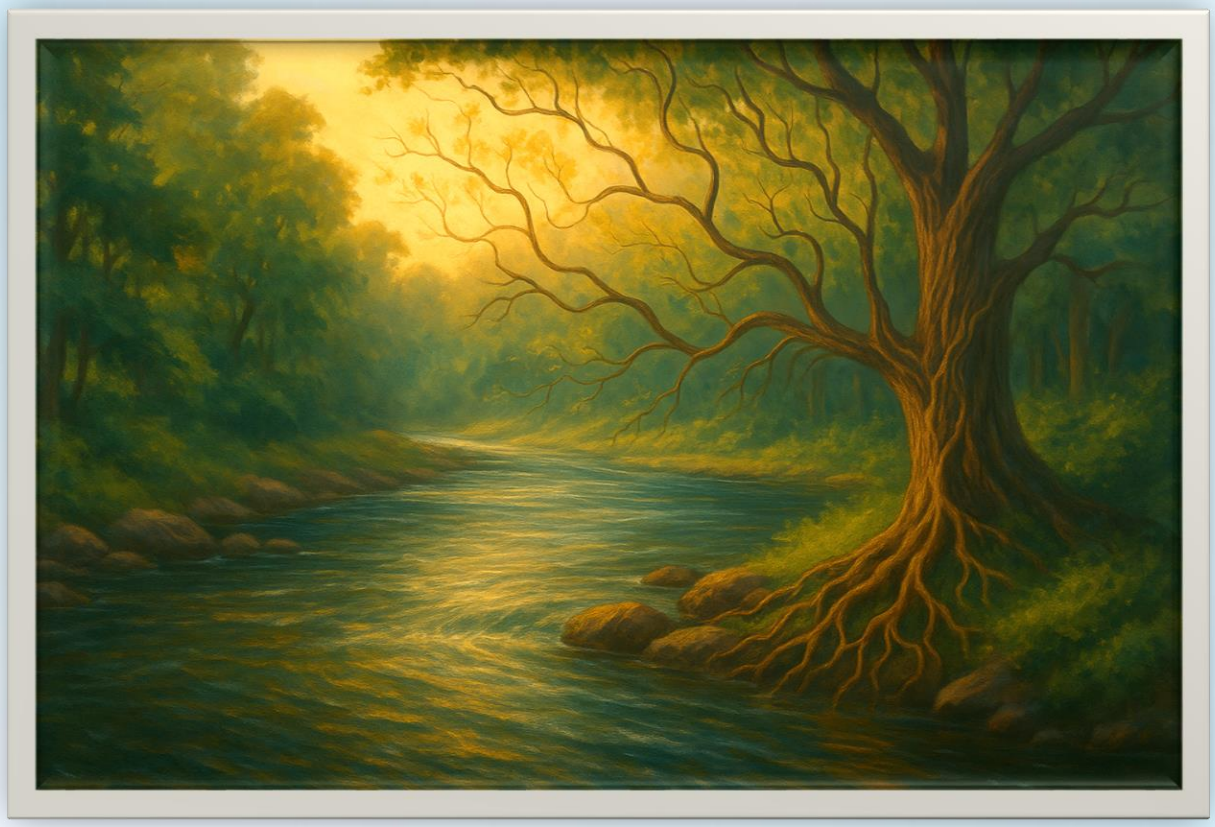
Huawei Technologies

ASSC 2025

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Why does time *flow*?

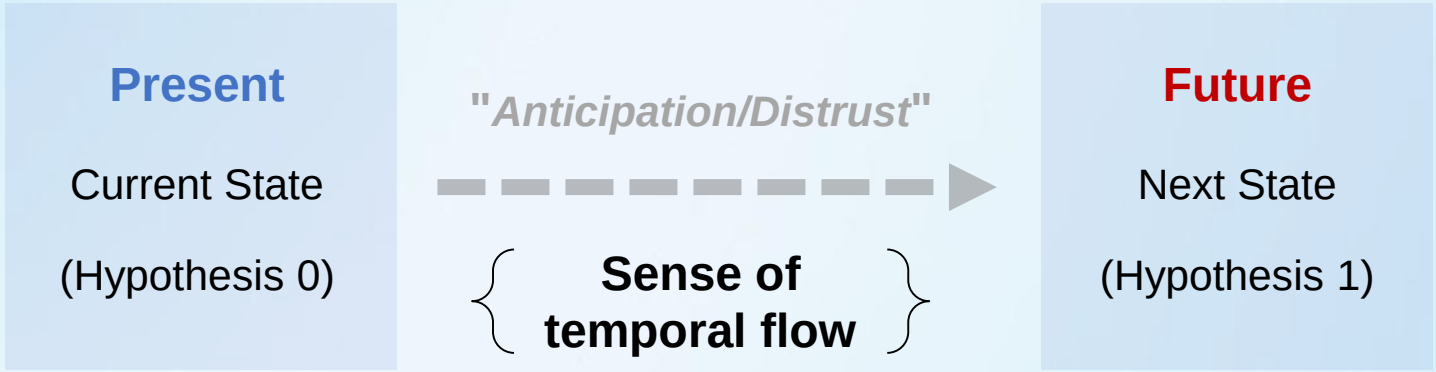


ChatGPT-4o, July 2025

We don't experience static "***nows***“ - we feel seamless forward progression

Stojić & Nadasdy (2024). Event as the central construal of psychological time in humans. *Frontiers in Psychology*, *15*, 1402903.

The brain constantly anticipates change

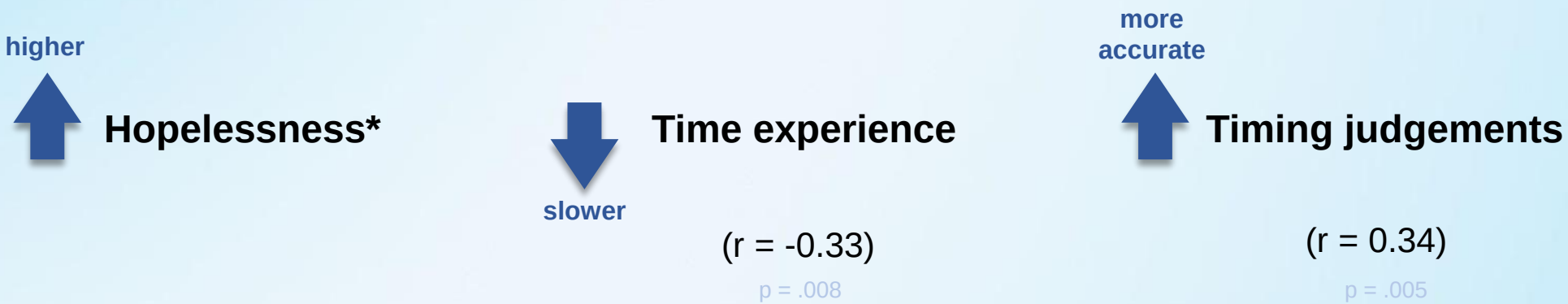


- Predictive processing suggests: Flow arises because brains expect change (**Hohwy et al., 2016**)
- System begins "distrusting the present" as soon as it settles on current explanation
- **Key question:** What's the actual computational mechanism?

Hohwy, Paton & Palmer (2016). Distrusting the present. Phenomenology and the Cognitive Sciences, 15, 315-335.

Some evidence: Hopelessness changes time perception

Kent et al. (2019): In healthy adults,



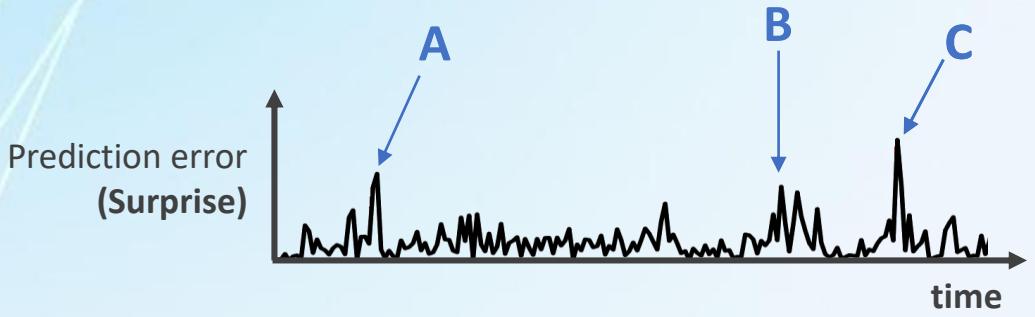
- Pattern *consistent with* "trusting the present longer“.
- **But:** Small sample, healthy participants, correlational data.
- **The computational mechanism remained unclear...**

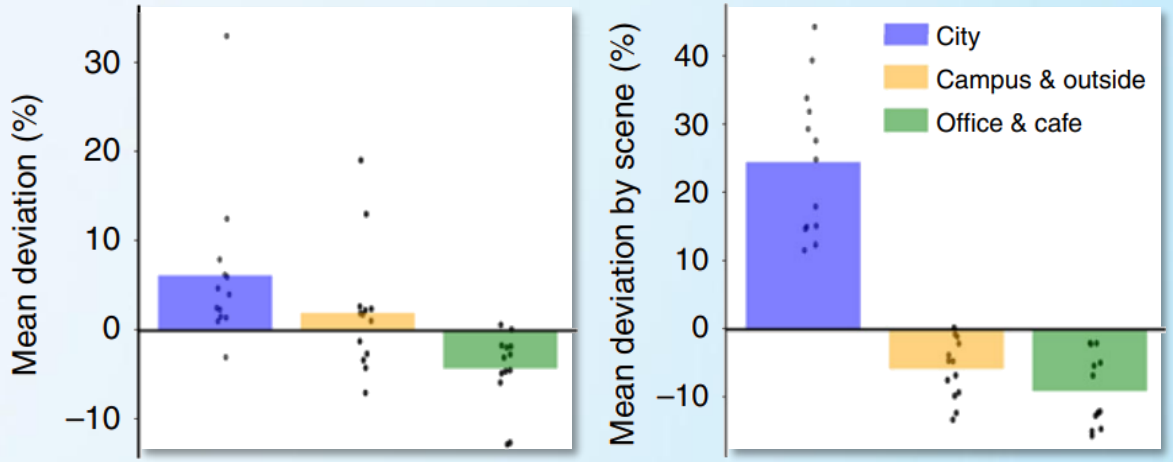
* Measured using the Beck Hopelessness Scale (BHS).

Kent, van Doorn, Hohwy & Klein (2019). Bayes, time perception, and relativity: The central role of hopelessness. Consciousness and cognition, 69, 70-80.

How about timing judgements

A compelling theory: The brain relies on measuring salient perceptual change to perform duration judgements.





Roseboom et al. (2019)

$f_\theta(\mathbf{A} + \mathbf{B} + \mathbf{C}) =$ duration judgements (sec)

However:





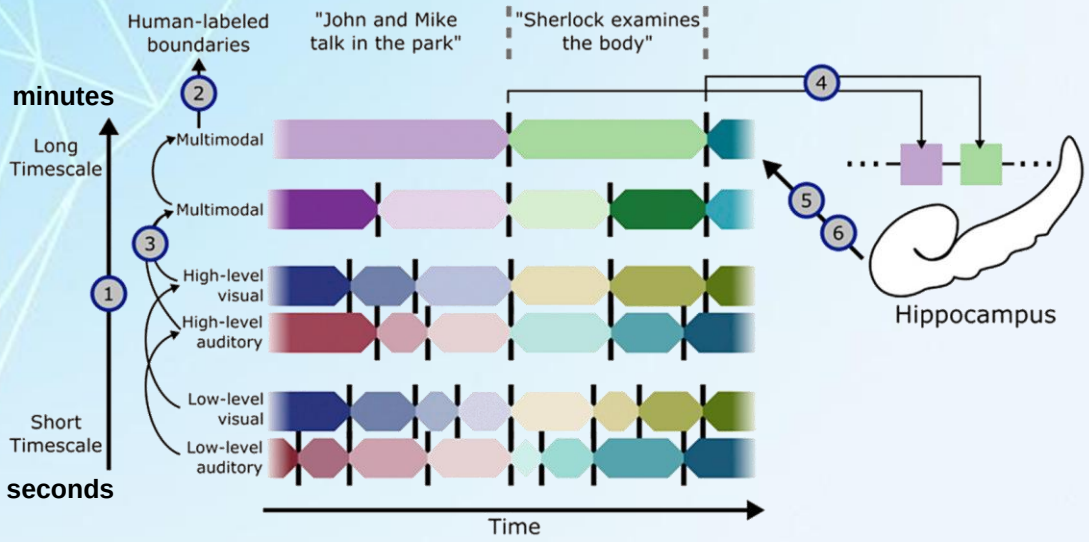
Roseboom et al. (2019)

Fountas et al. (2022)

Sherman et al. (2022)

Roseboom et al. "Activity in perceptual classification networks as a basis for human subjective time perception." Nature communications (2019)
Fountas et al. "A predictive processing model of episodic memory and time perception." Neural computation (2022)
Sherman et al. "Trial-by-trial predictions of subjective time from human brain activity." PLOS Computational Biology (2022)

The brain carves experience into nested event hierarchies



1. Hierarchy of timescales in different brain regions.
2. High-level regions: event boundaries human-identifiable.
3. Abstract content is drawn from multiple input modalities.

Baldassano et al. (2017)

Multiple neuroimaging evidence since then.

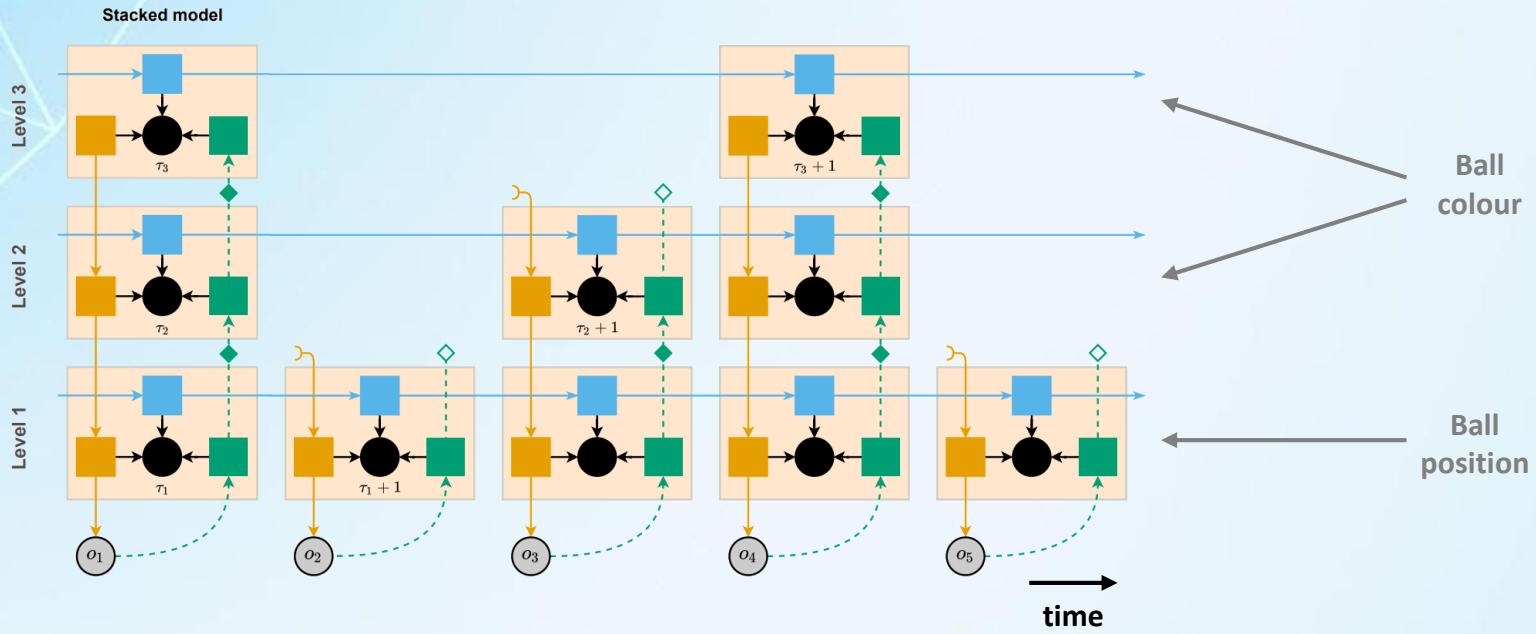
Geerligs et al. (2022); **Michelmann et al. (2023)**

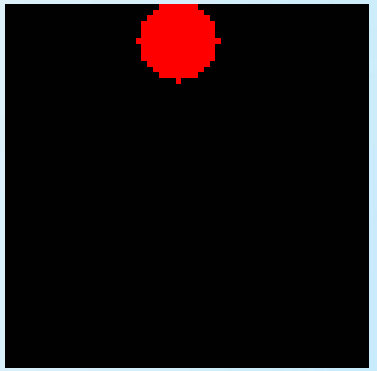
Crucially: Not all perceptual change is salient. Some is anticipated.

Proposal: This nested event segmentation **IS** the computational engine of temporal flow.

Baldassano et al. "Discovering event structure in continuous narrative perception and memory." Neuron (2017)
Geerligs et al. A partially nested cortical hierarchy of neural states underlies event segmentation in the human brain. eLife (2022)
Michelmann et al. Evidence That Event Boundaries Are Access Points for Memory Retrieval. Psychol. Sci. (2023)

We built an AI that learns temporal hierarchies like the brain





Toy example video

Key insight: Layers only update when they detect meaningful change.

- We built a hierarchical model (VPR) that learns from video (**Zakharov et al. 2022a**).
- Also explored how the system can learn *when* to anticipate a change (**Zakharov et al. 2022b**).

Zakharov, Guo & Fountas, Variational Predictive Routing with Nested Subjective Timescales, ICLR 2022a

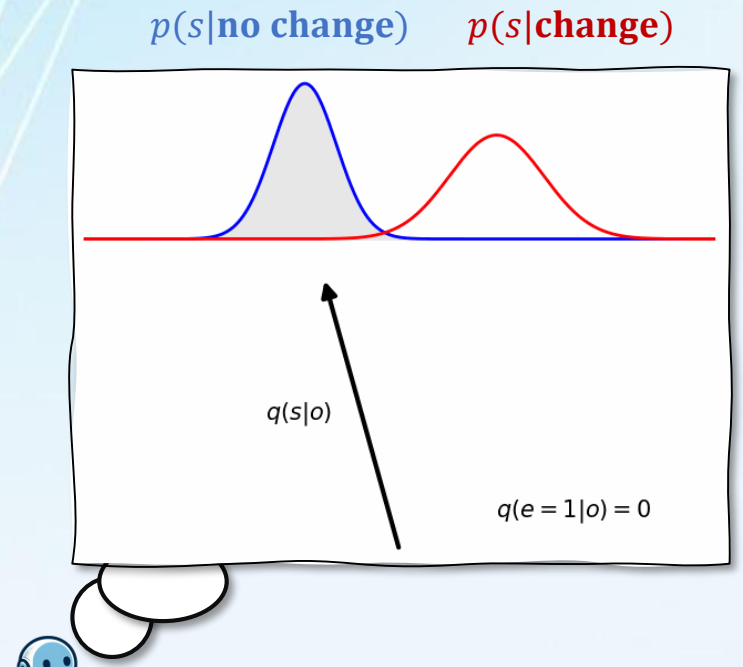
Zakharov, Guo & Fountas, Long-horizon video prediction using a dynamic latent hierarchy, 2022b

An "event" occurs when "change" explains more than "stability"

The Core idea: At every moment, each layer of the hierarchy runs a simple hypothesis comparison:

Hypothesis 0: "The world stayed the same"

Hypothesis 1: "The world changed as I predicted"



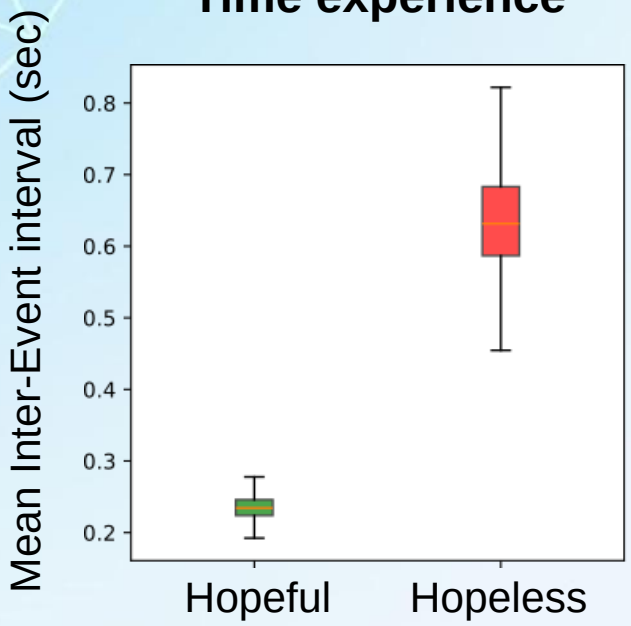
- **Hypothesis 1** wins → event declared, beliefs update,

if: $$E_{\text{sensory data}} \log \frac{p(s|\text{change})}{p(s|\text{no change})} > T$$

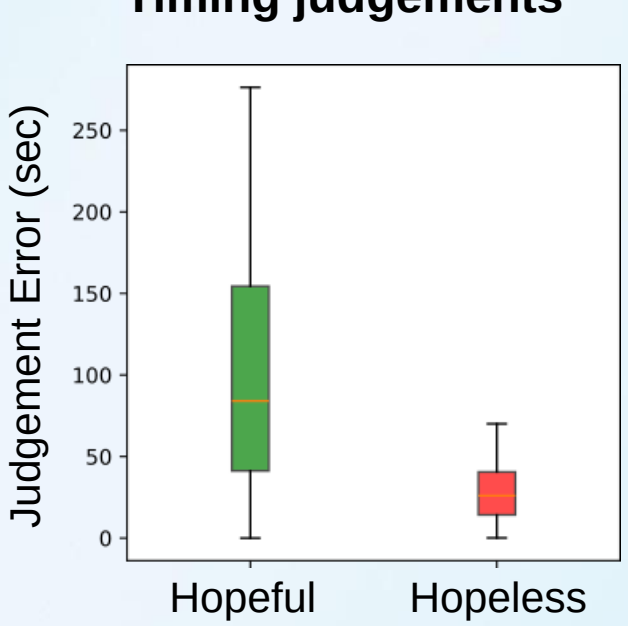
- Hence, the model continuously performs **Bayesian model comparison**.
- This is formal implementation of "distrusting the present"

This framework predicts Kent et al.'s findings

Time experience



Timing judgements



Hopelessness vs **Time experience**

(r = -0.49)

p = .00

Hopelessness vs **Time judgements**

(r = 0.91)

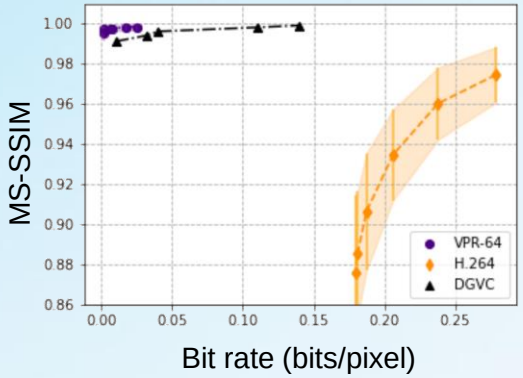
p = .00

Hopeless people have reduced precision on "change" priors → fewer detected events

This isn't just theory - it works in practice

The same mechanism achieved state-of-the-art performance in:

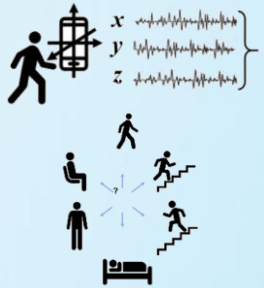
A) Video compression (*Breitschwerdt et al., 2022*)



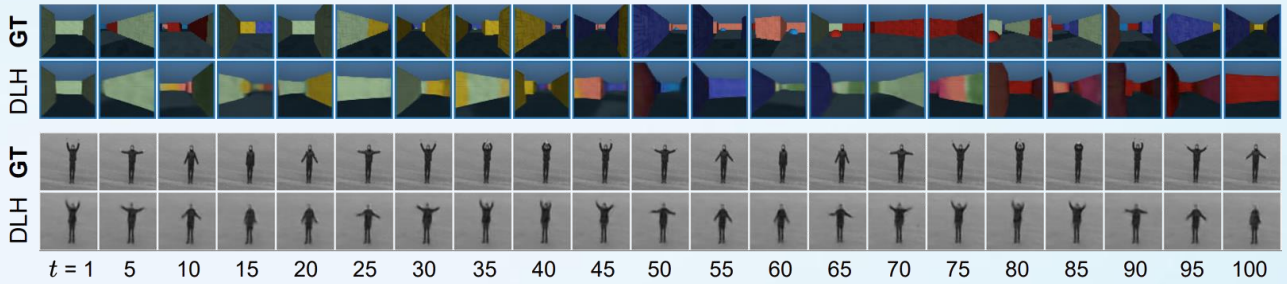
- DGVC
- H.264
- **VPR**

B) Changepoint detection (*Gourmet et al., 2022*)

Detection margin	60	100
FLOSS	0.3088	0.3913
aHSIC	0.2308	0.3134
RuLSIF	0.3433	0.4999
ESPRESSO	0.2879	0.4233
KL-CPD	0.4785	0.4726
TS-CP^2	0.40	0.4375
VPR (shallow)	0.5049	0.5437
VPR (3 levels)	**0.5252**	**0.6023**



C) Far-sighted video generation (*Zakharov et al., 2022*)



D) LLM compression (*Wieser et al., In Preparation*)

Coming soon…

Summary

- Temporal flow emerges from continuous Bayesian change detection.
- This single mechanism explains event segmentation, efficient learning, timing, AND subjective time experience.
- Provides **large-scale** computational foundation for established behavioral findings using **real-world stimuli**.
- Critics asked if predictive coding can explain time-consciousness (**Nishida, 2022**) - **our model says yes!**

Testable predictions:

1. High-level events trigger lower-level boundary cascades within 200ms.
2. Attention modulates boundary timing at specific hierarchical levels.
3. Fewer boundaries for unpredictable vs predictable changes.
4. Depression/autism show altered hierarchical boundary coupling patterns.

Bogotá, J. D. (2023). Can the predictive mind represent time? Phenomenology and the Cognitive Sciences, 1-21.

Thank you!

Questions?

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