What does it mean to be in the loop?

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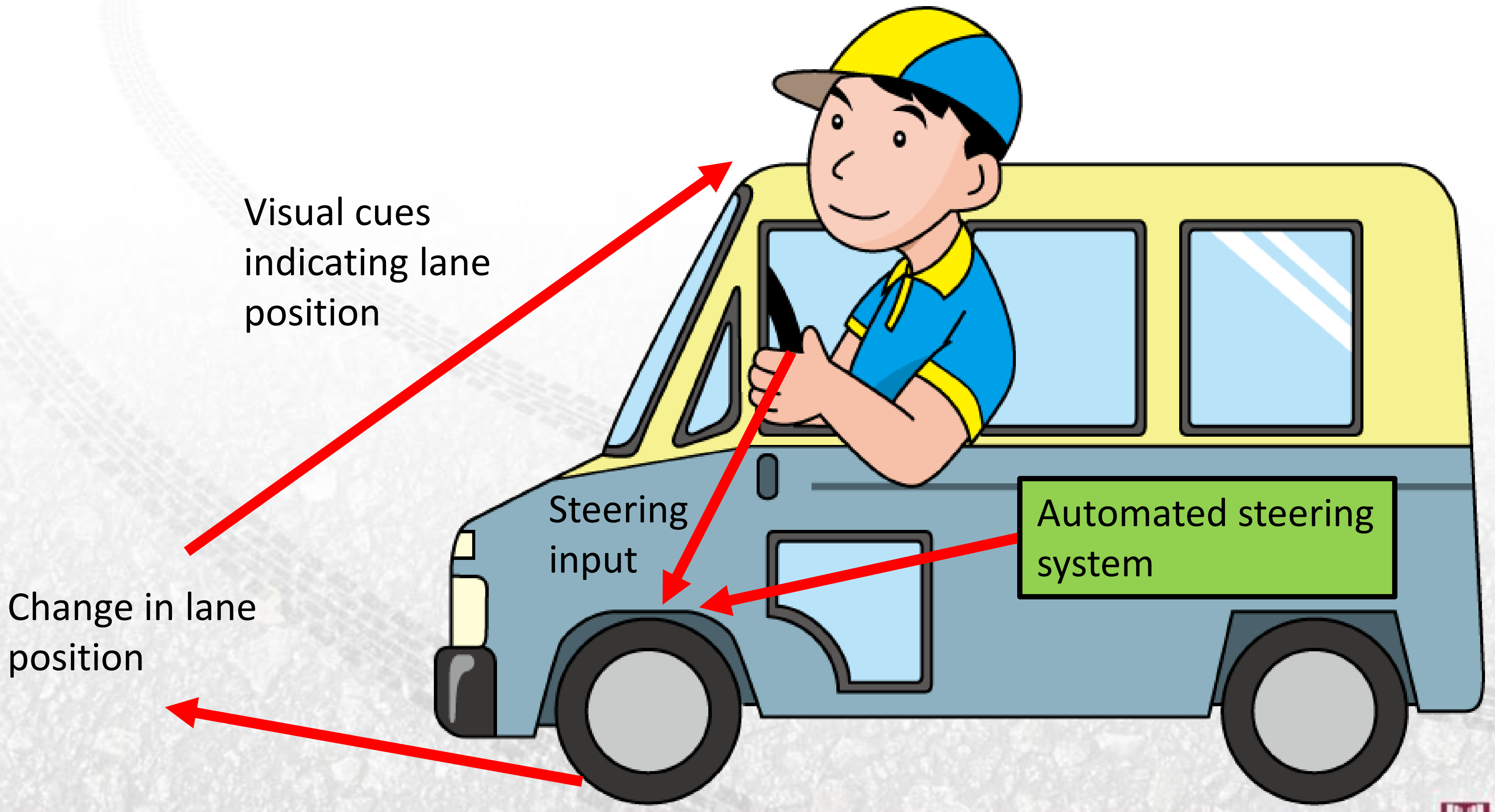
Driving automation systems

Levels of automation (JSAE 3016)

Level	Name	Narrative definition	*DDT*		*DDT fallback*	*ODD*
			Sustained lateral and longitudinal vehicle motion control	***OEDR***		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

The loop – a simplistic view

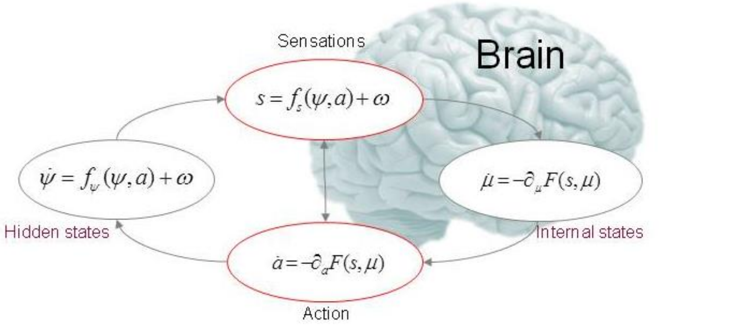


What do we actually mean by being in the loop?

- What is "the loop"?
- What does it mean to be in it?
- What does it mean to be out of it?
- Can we speak of different loops related to different levels of the driving task (e.g., operational, tactical, strategic)?
- Does being in the loop require active processing (e.g., steering, braking)?
- Does being in the loop require controlled (conscious, effortful) processing or is automatized (skilled, unconscious, effortless) performance sufficient?
- Should being in the loop be viewed as an all-or-none phenomenon or as a continuum?

Predictive Processing

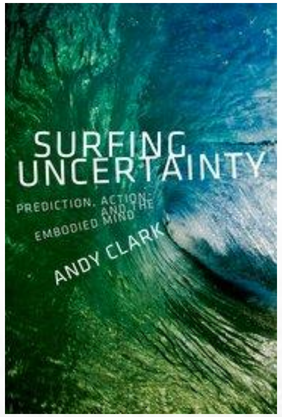
Neuroscience



Karl Friston, The free energy formulation

Friston, K. J. 2010 The Free-energy Principle: A Unified Brain Theory? *Nature Reviews Neuroscience* 11(2):127–38.

Cognitive science



Andy Clark, predictive processing

Clark, A. 2016. Surfing uncertainty. Oxford: Oxford University Press.

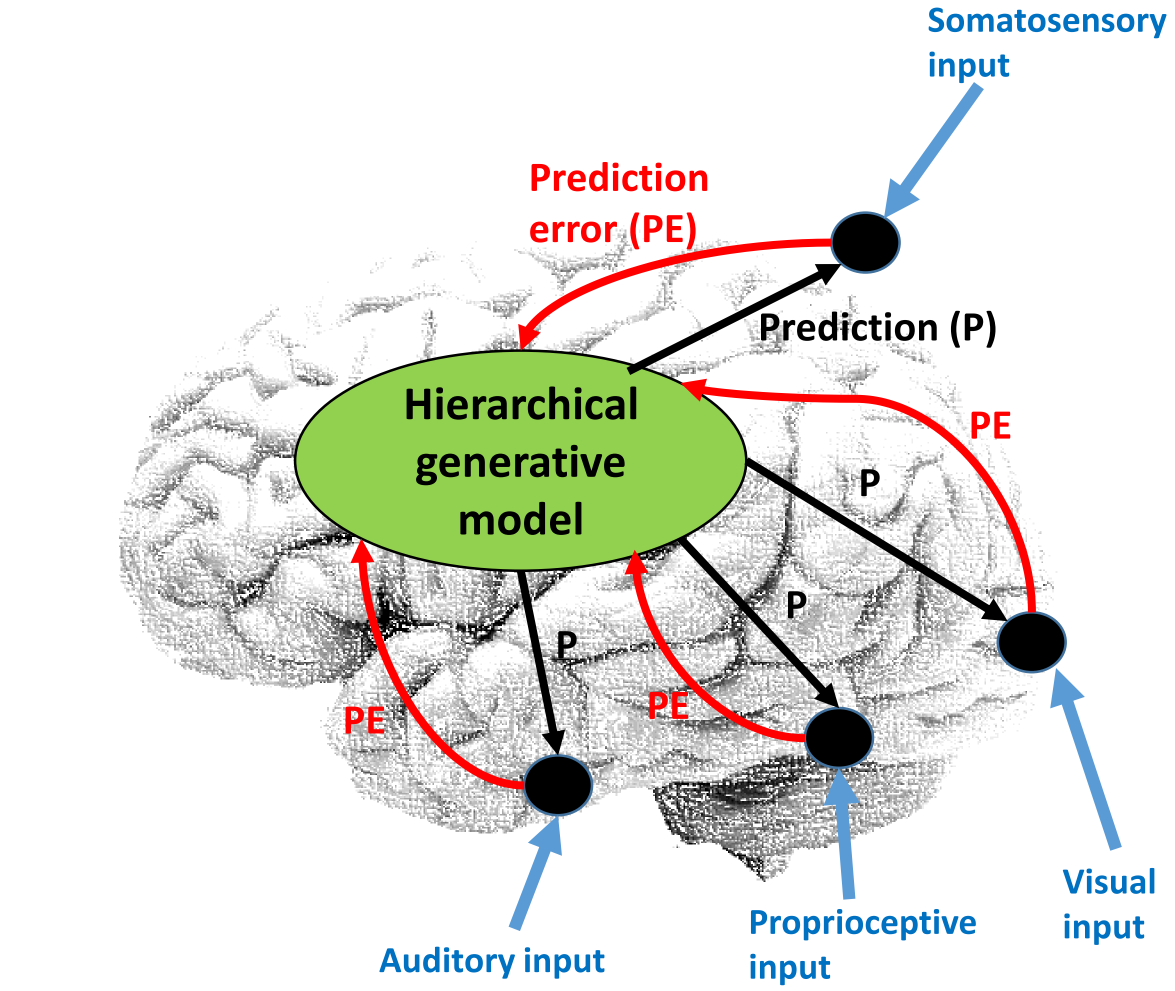
Applied human factors

Engström, J., Bärgman, J., Nilsson, D., Bianchi Piccinini, G.F. , Seppelt, B., Markkula, G., Victor, T. (2017). Great expectations: A predictive processing account for automobile driving. *Theoretical Issues in Ergonomics Science*, in press.

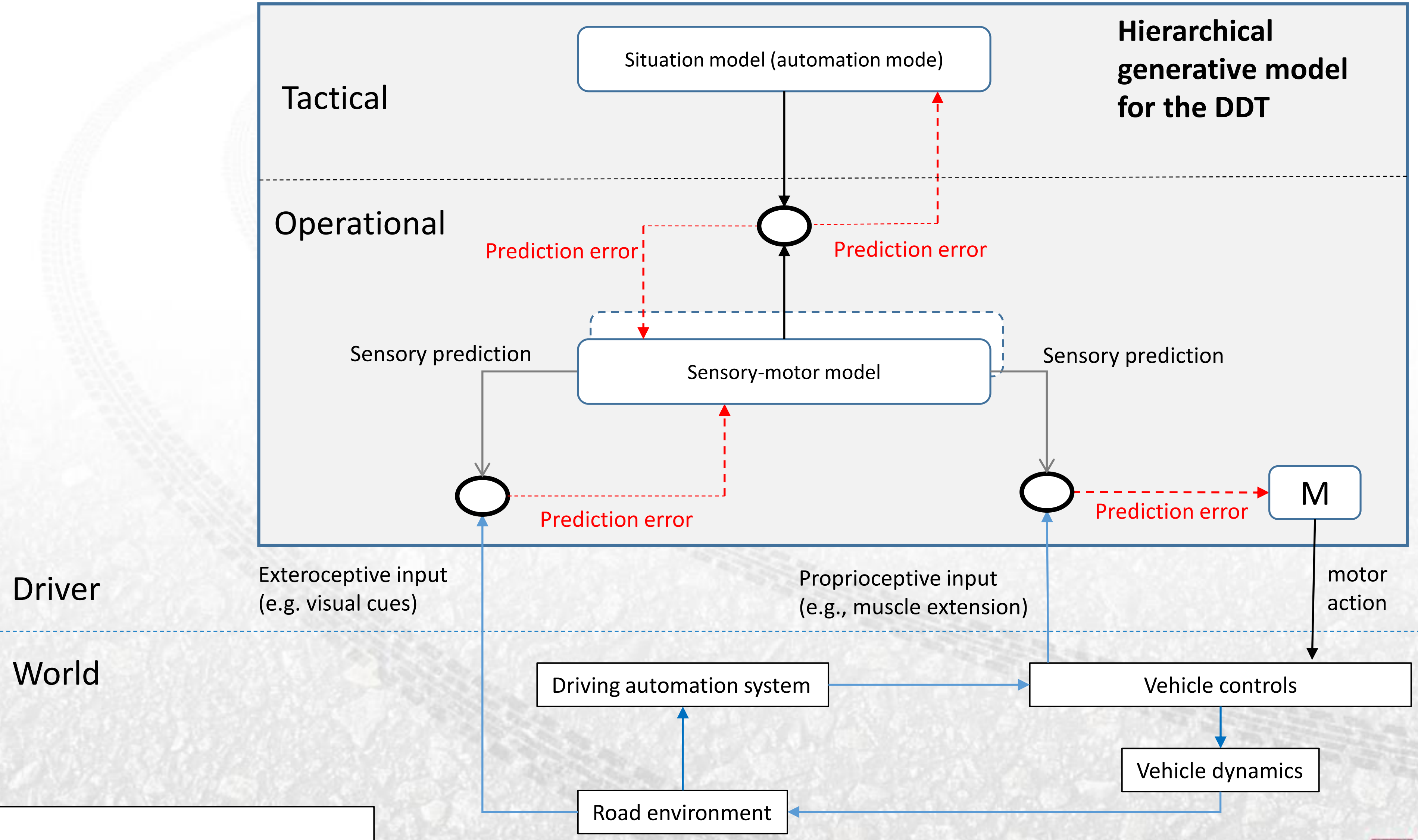
QUADRAE
Quantitative Driver Behaviour Modelling for Active Safety Assessment Expansion

Predictive processing

- **Unifying principle:** All cognition and behavior can be understood in terms of *predictions and the minimization of prediction errors*
- Predictions are continuously generated in all sensory modalities by a **hierarchical generative model** (a special kind of "mental model")
- Sensory prediction errors can be minimized by:
  - Updating the prediction (perception)
  - Aligning the sensory input with the prediction (action)
- Minimizing prediction errors by perception and action = (active) **inference**

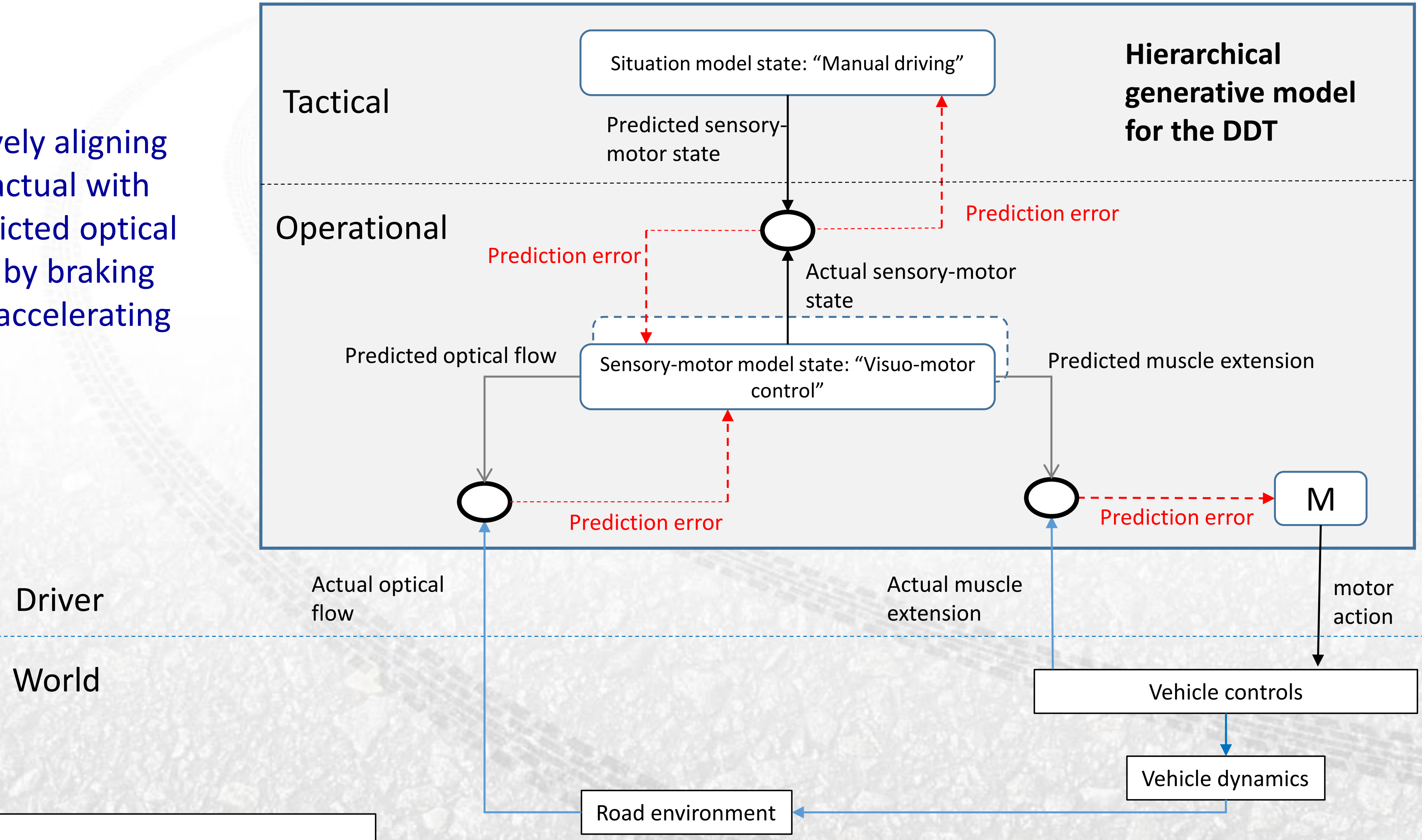


Application to automated driving



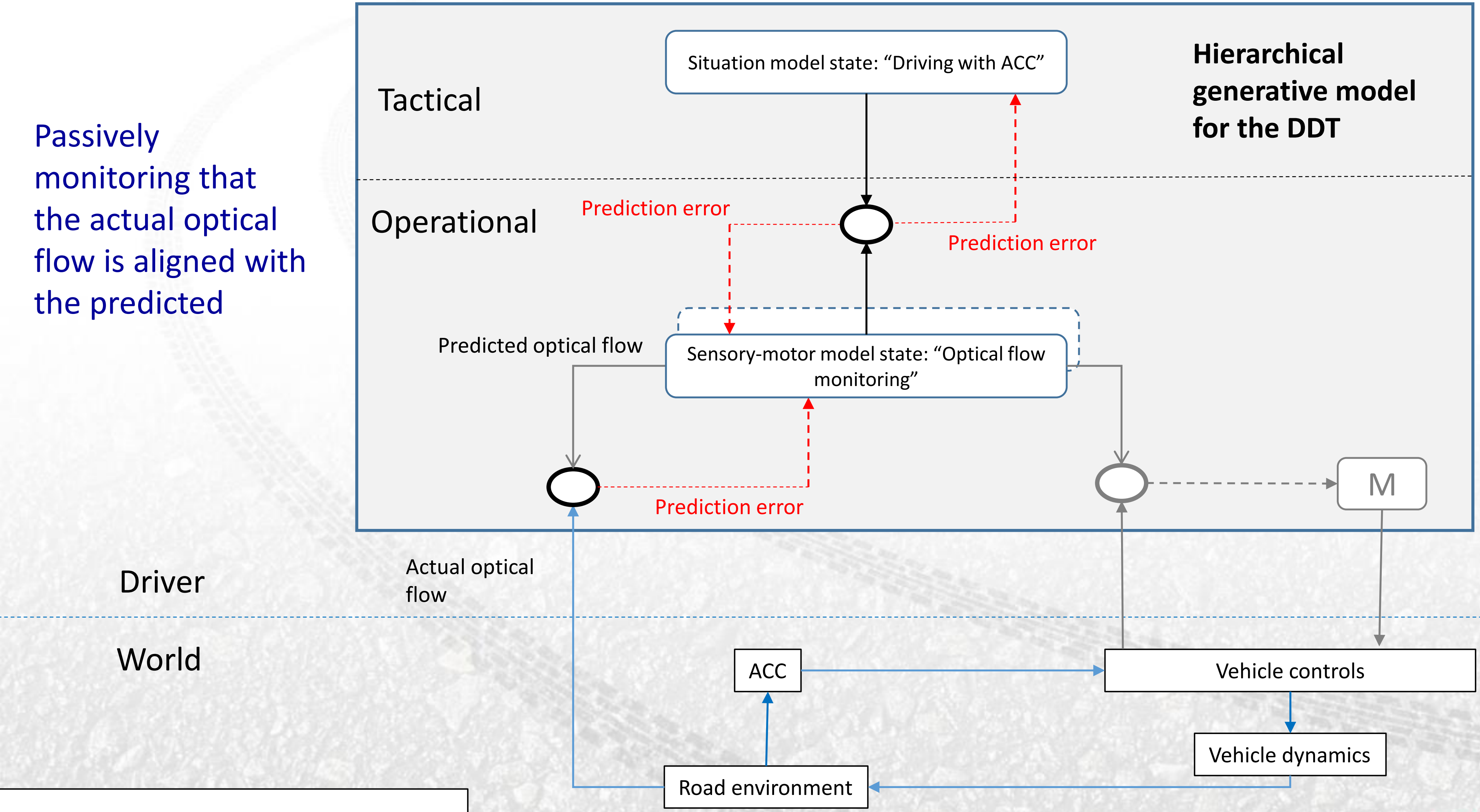
Example: Manual driving

Actively aligning the actual with predicted optical flow by braking and accelerating



Example: Driving with Adaptive Cruise Control (L1 automation)

Passively monitoring that the actual optical flow is aligned with the predicted



So, what do we mean by being in the loop? (1)

- What is "the loop"?
  - The process of inference = generating predictions and cancelling prediction errors by perception and/or action
- What does it mean to be in it?
  - Being in the loop for driving subtask X = Being engaged in inference (generating predictions and cancelling prediction errors) related to X
- What does it mean to be out of it?
  - Being out of the loop for driving subtask X = No predictions are generated relative to subtask X
- Can we speak of different loops related to different levels of the driving task (e.g., operational, tactical, strategic)?
  - Yes, inference at the operational level relates to predictions about sensory input. Inference at higher levels (tactical, strategic) relates to predictions about the *state* of the level below
  - One can thus be in the loop at the tactical level but out of the loop at the operational level

So, what do we mean by being in the loop? (2)

- Does being in the loop require active processing (e.g., steering, braking)?
  - No, since passive monitoring also involves generating predictions and cancelling prediction errors (but here only by perception=updating the model state generating the prediction)
  - The active-passive processing distinction is important but does not define OOTL
- Does being in the loop require controlled (conscious, effortful) processing or is automatized (skilled, unconscious, effortless) performance sufficient?
  - The latter. Inference take place in both controlled (novel tasks) and automatized (after practice) performance "modes"
- Should being in the loop be viewed as an all-or-none phenomenon or as a continuum?
  - As a continuum

Example: Level 1-2 automation

- *Critical distinction:* Is the driver is in the loop for the OEDR task at the operational level or only at the tactical level?
- According to PP, depends on whether the driver generates predictions at the operational level

SAE J3016

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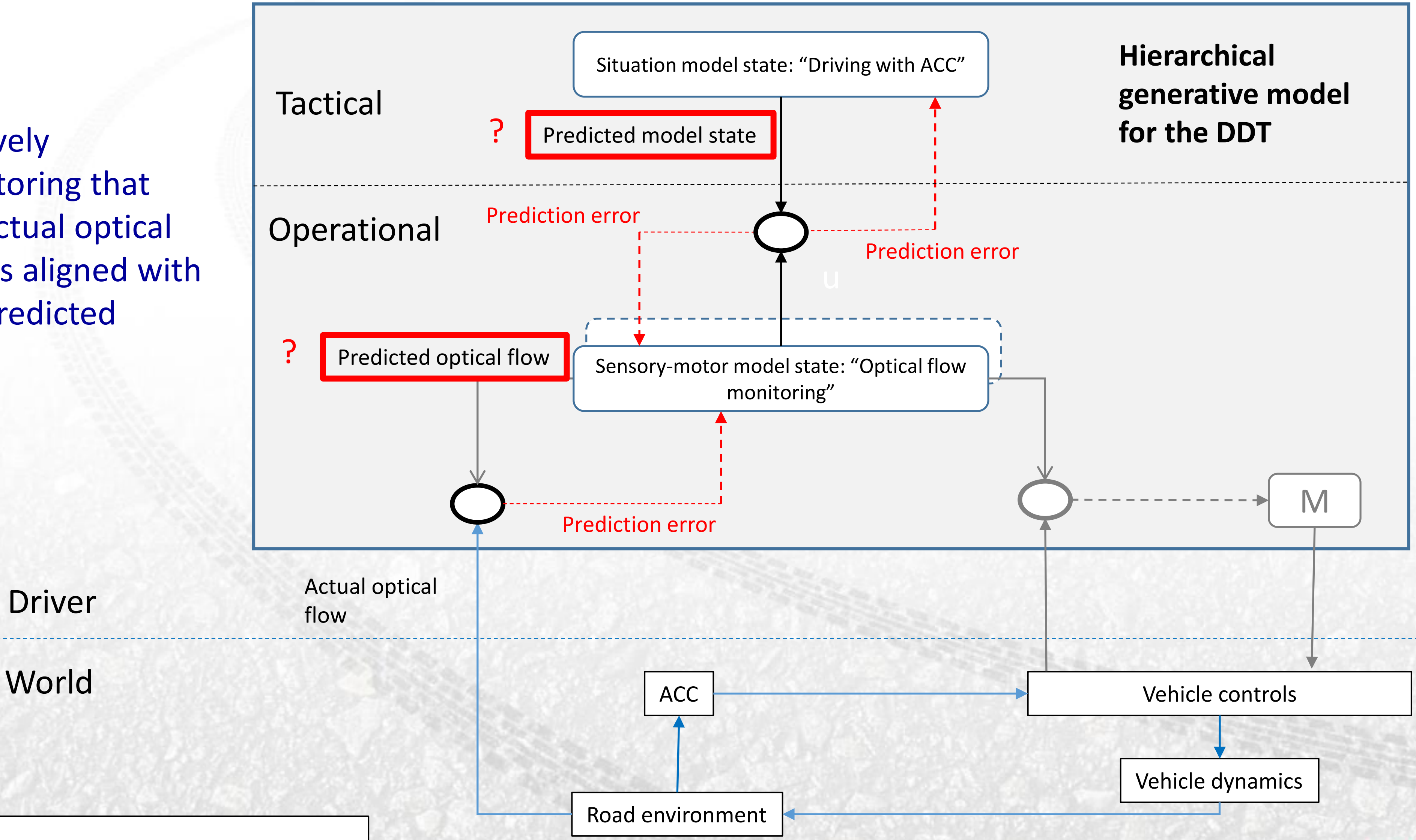

Conclusions

- Being in or out-of-the-loop concept is a key concept in understanding driving performance related to automated driving
- However, lacks a precise mechanistic definition
- Proposed such a definition based on the predictive processing framework originating in neuroscience and cognitive science
- Next question: Can the predictive processing help us to better understand why drivers get out of the loop (e.g., due issues with complacency, sustained attention and fatigue)?
- Conceptual and computational models based on these ideas are currently underway

How do drivers get out of the loop?

Two distinct mechanisms

1. Vigilance and complacency problems
   - PP: Information sources not contributing to overall minimization of prediction error will not be monitored
   - Related to lack of stimulation/information, passive fatigue, cognitive bias
   - Selection problem
2. Reduced arousal
   - PP: Reduced activation level in the generative model
   - Related to sleep-related factors (circadian and homeostatic) and task-related factors (e.g., time on task)
   - Can be modelled in terms of the rate of evidence accumulation (see Markkula and Engstrom, 2017; presented tomorrow at 10.30)
   - Activation problem