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A hierarchical task-based control model of speech incorporating sensory feedback

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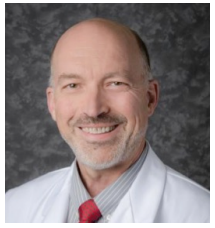
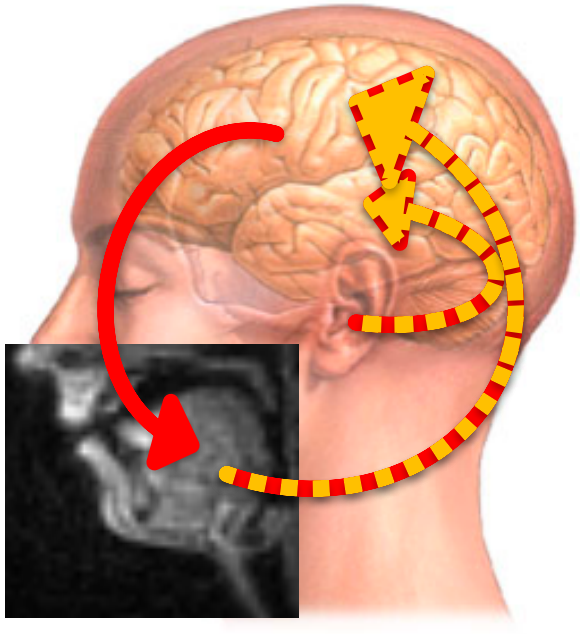
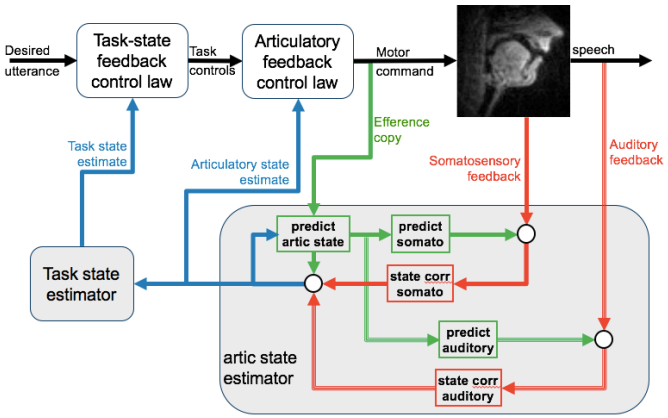


*equal contribution

The sensory system in speech production

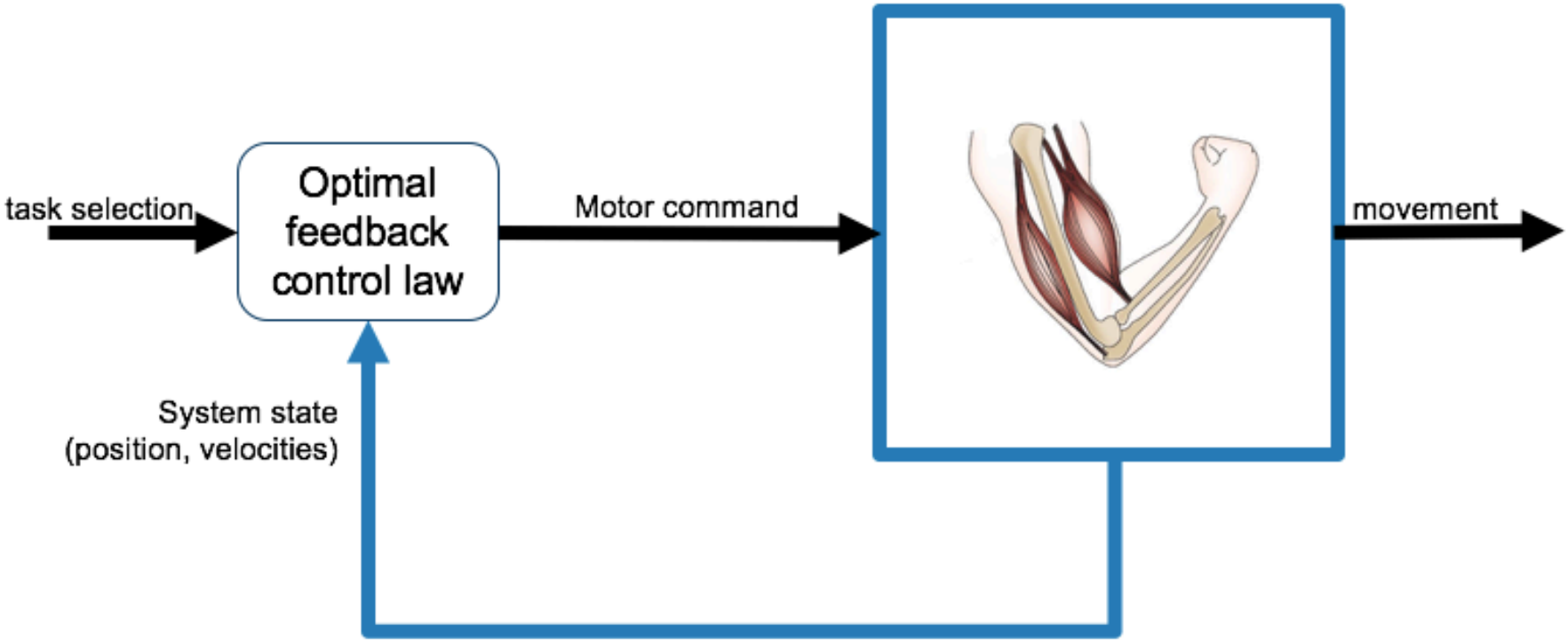
- Speech is responsive to sensory feedback
  - Delayed auditory feedback disrupts fluent speech
    (Lee, 1950; Yates, 1963)
  - Speakers compensate for all manner of auditory and somatosensory feedback perturbations
    (e.g. Houde 1998; Burnett 1998; Tremblay 2003;…)
- But speech is not dependent on sensory feedback
  - Post-lingually deafened adults can be intelligible for decades
    (Waldstein, 1990; Cowie and Douglas-Cowie, 1992)
  - Speech is highly intelligible during oral sensory and auditory deprivation (though articulatory precision is affected)
    (Scott and Ringel, 1971; Ringel and Steer, 1963)





Feedback-Aware Control of Tasks in Speech (FACTS)

FACTS is based on a domain-general State Feedback Control architecture



Scott, S. H. (2004): *Nature Reviews Neuroscience, 5*(7), 534-546.

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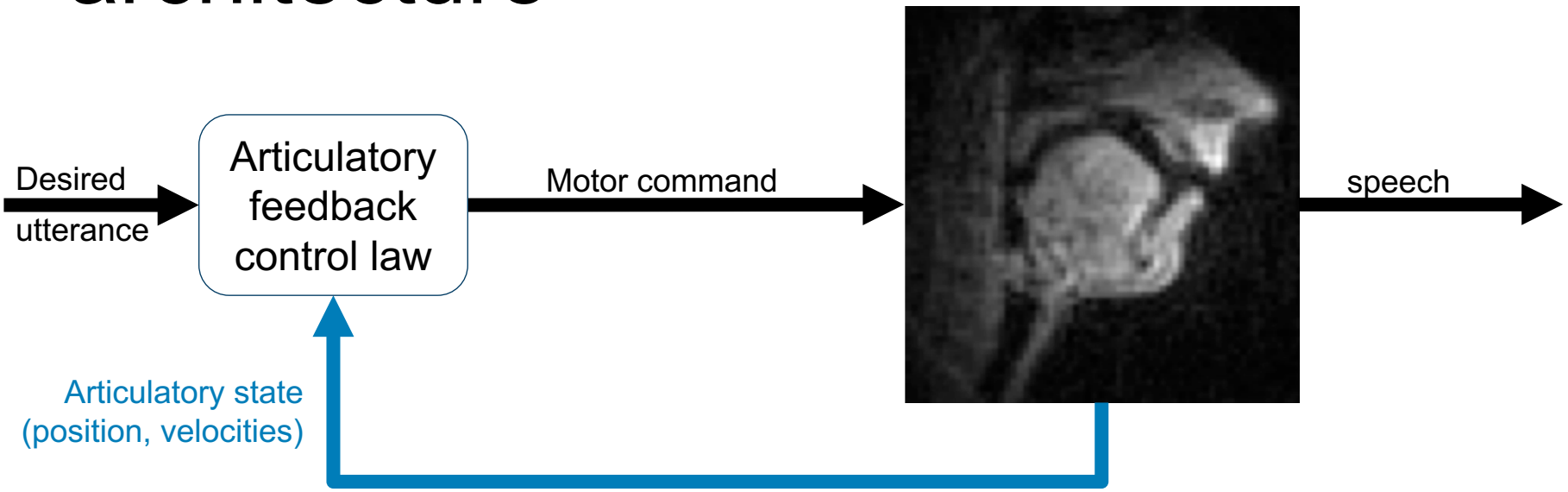

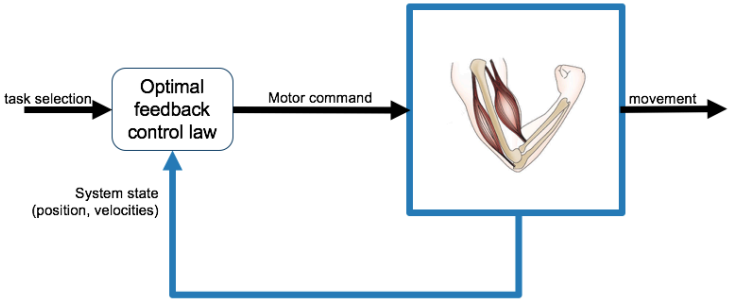

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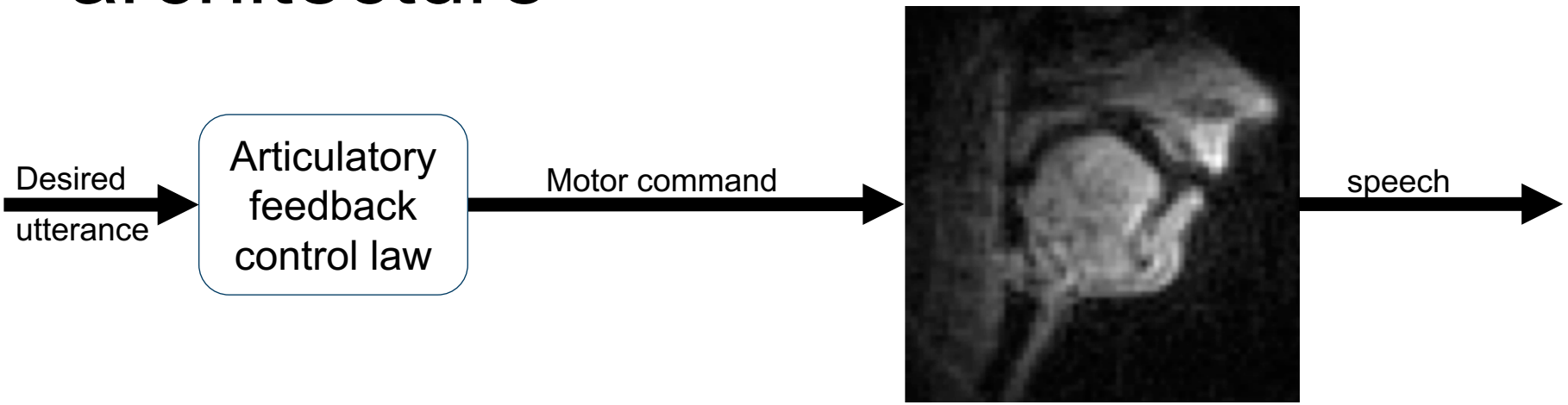

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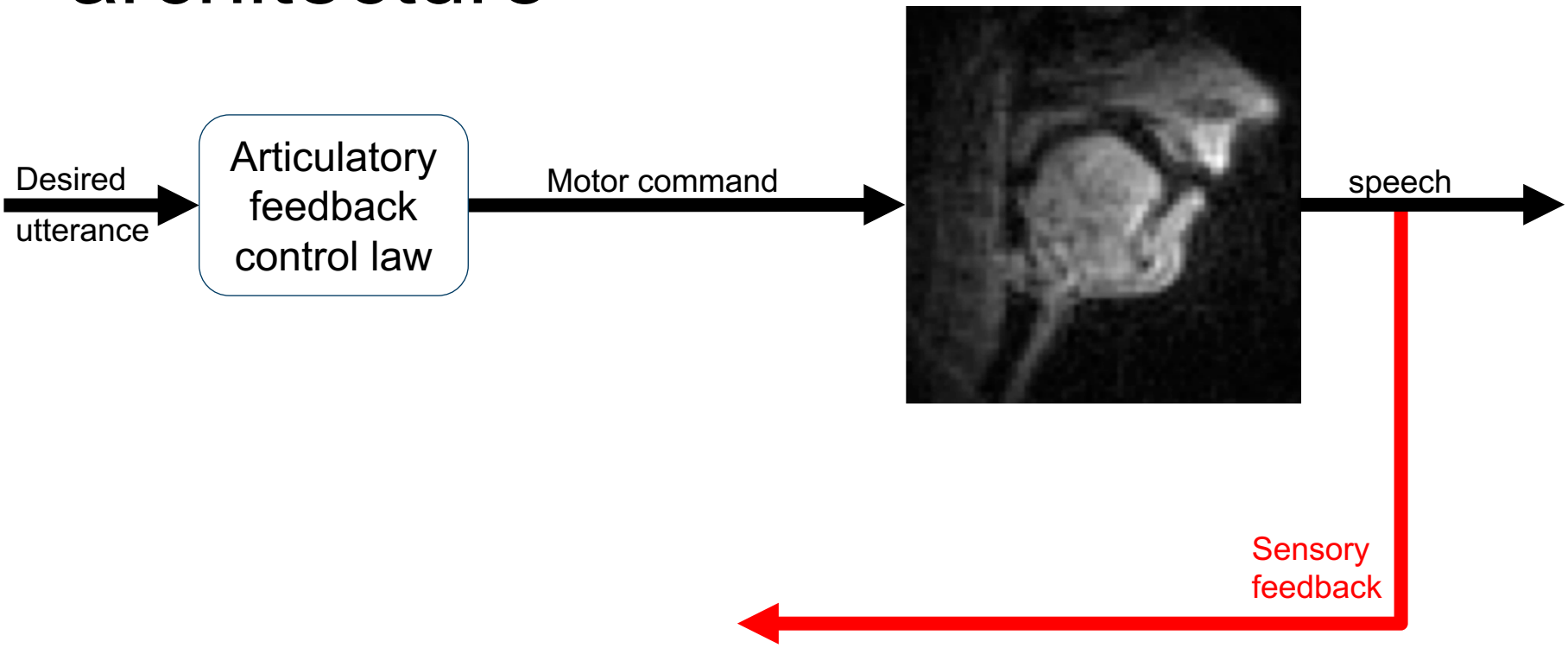

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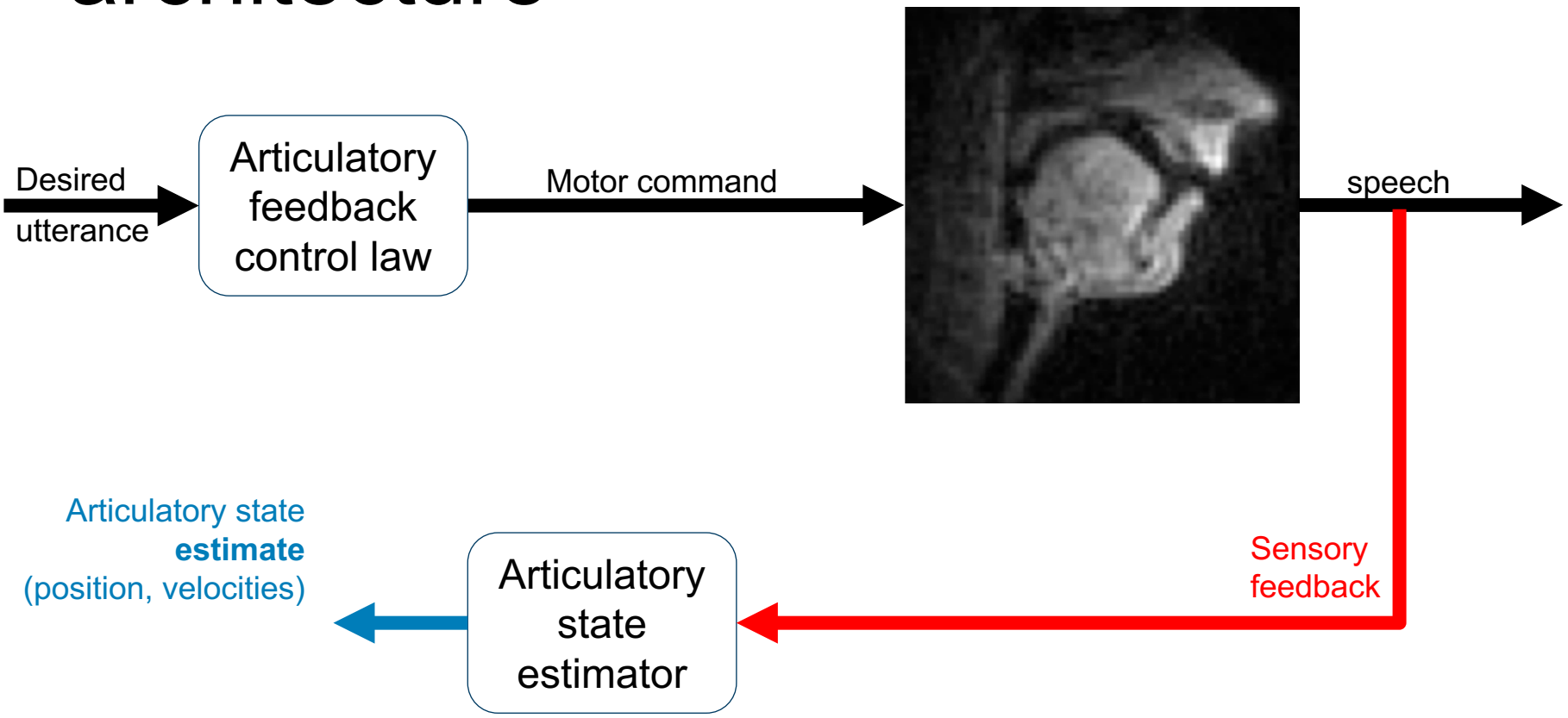

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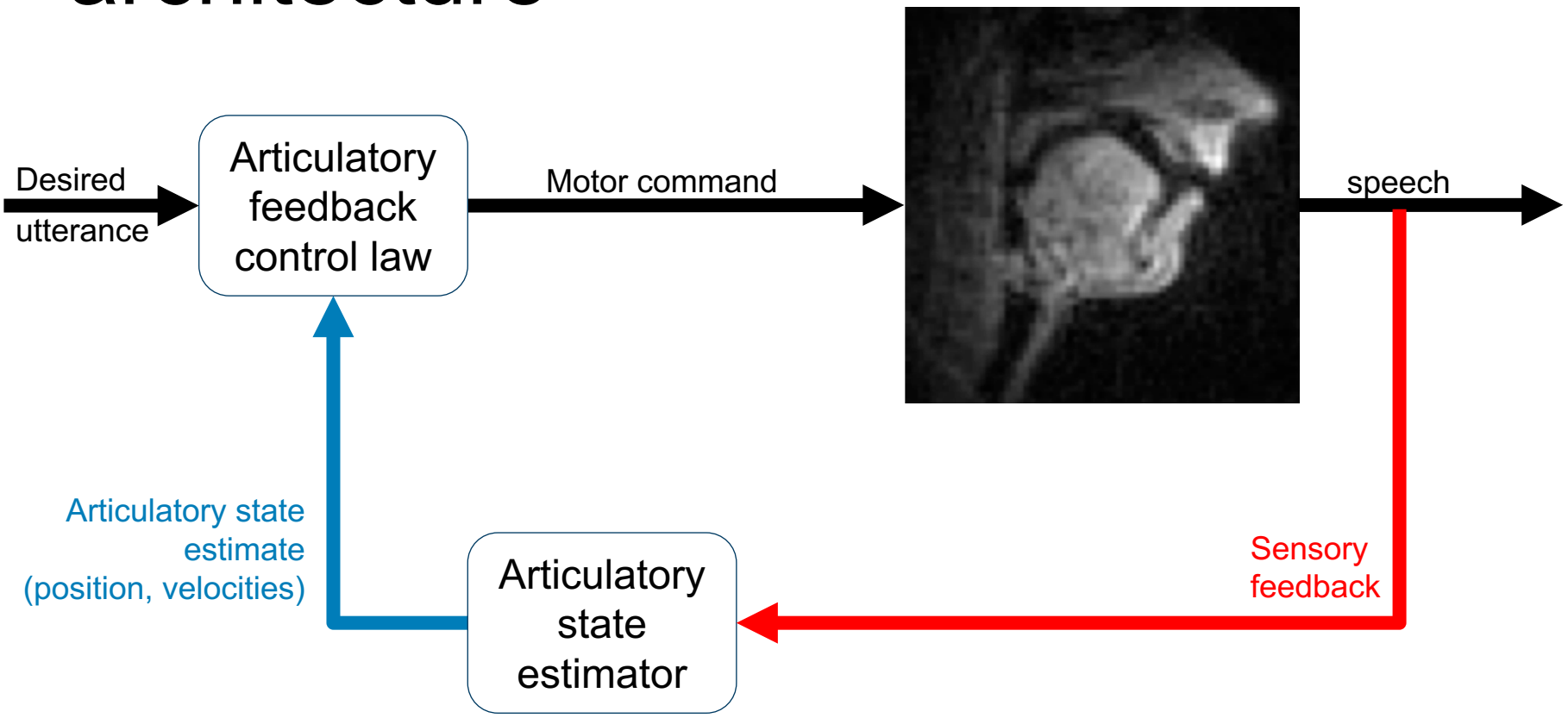

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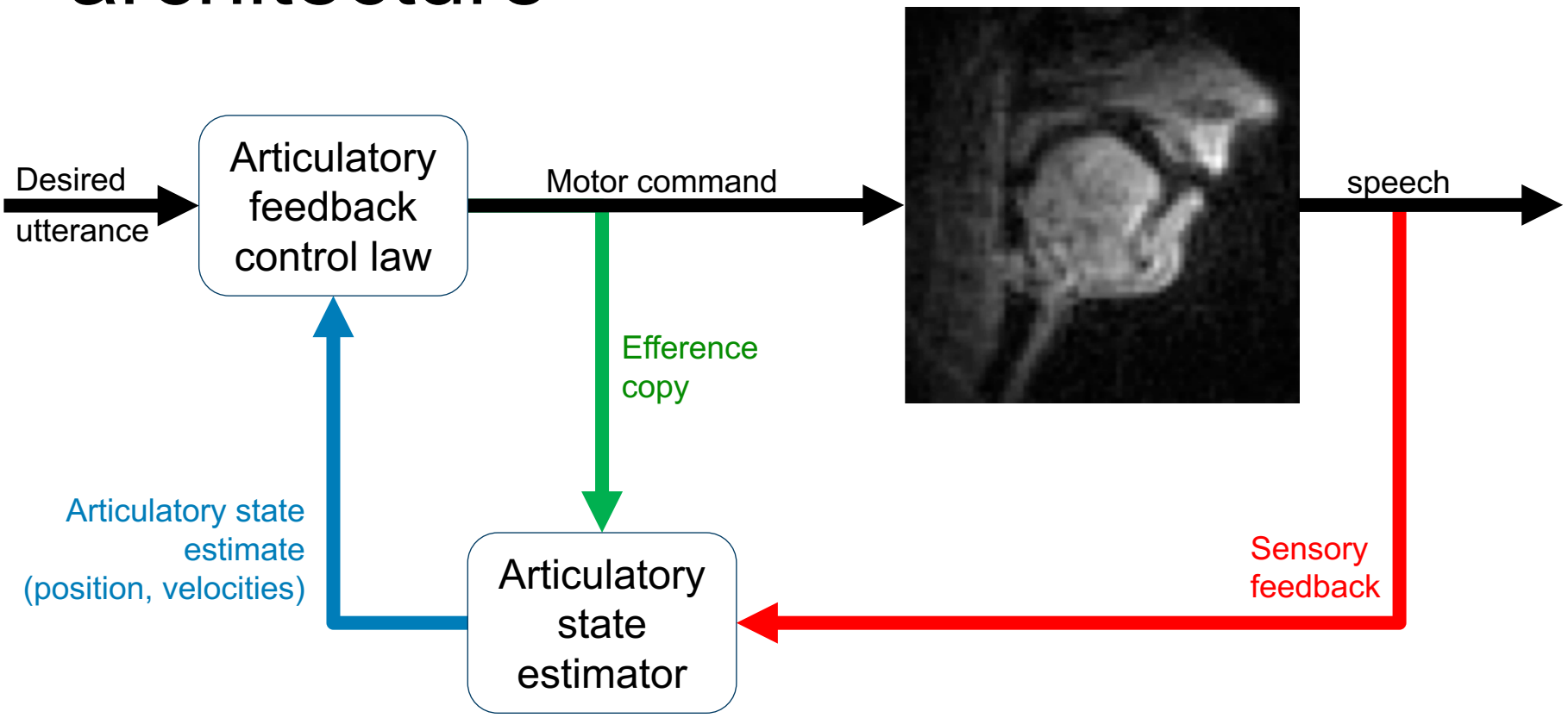

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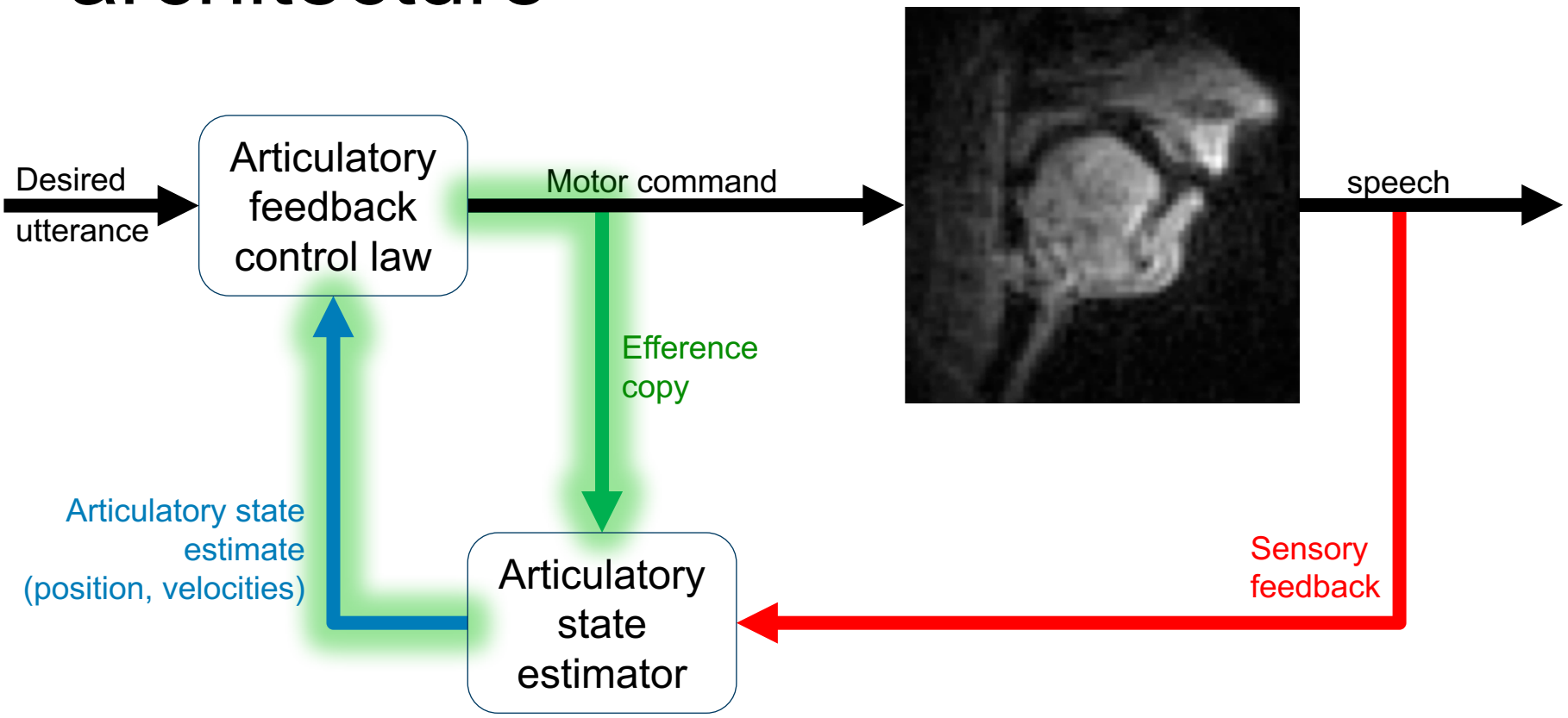

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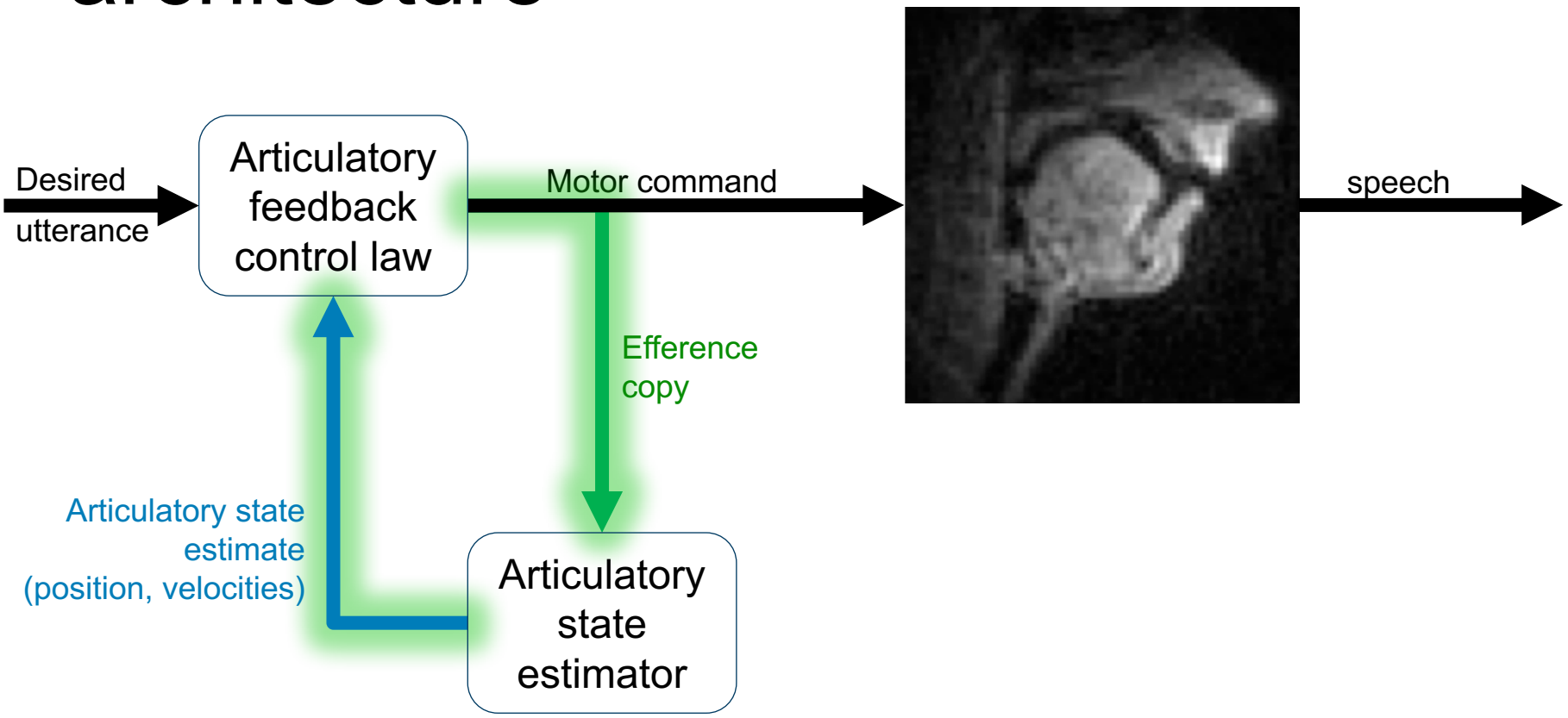

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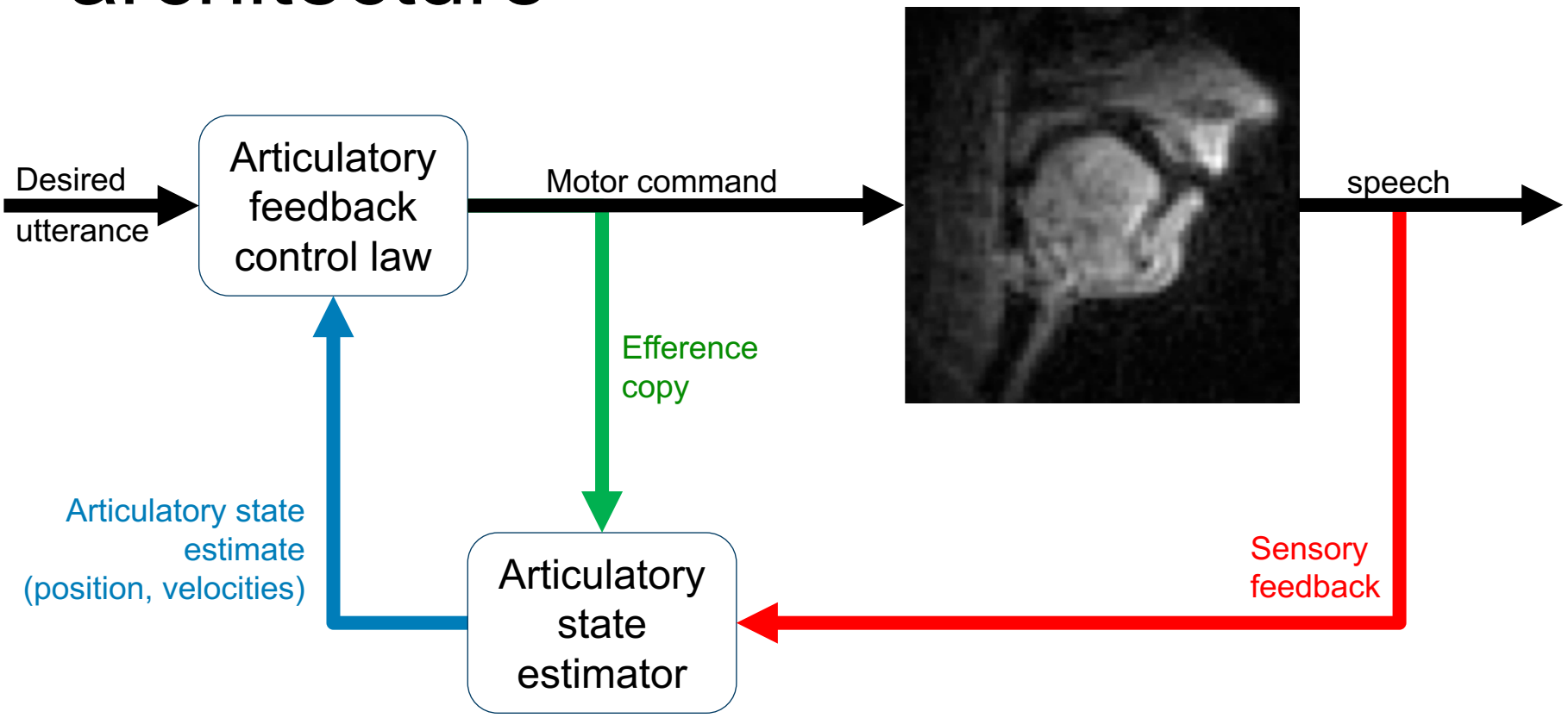

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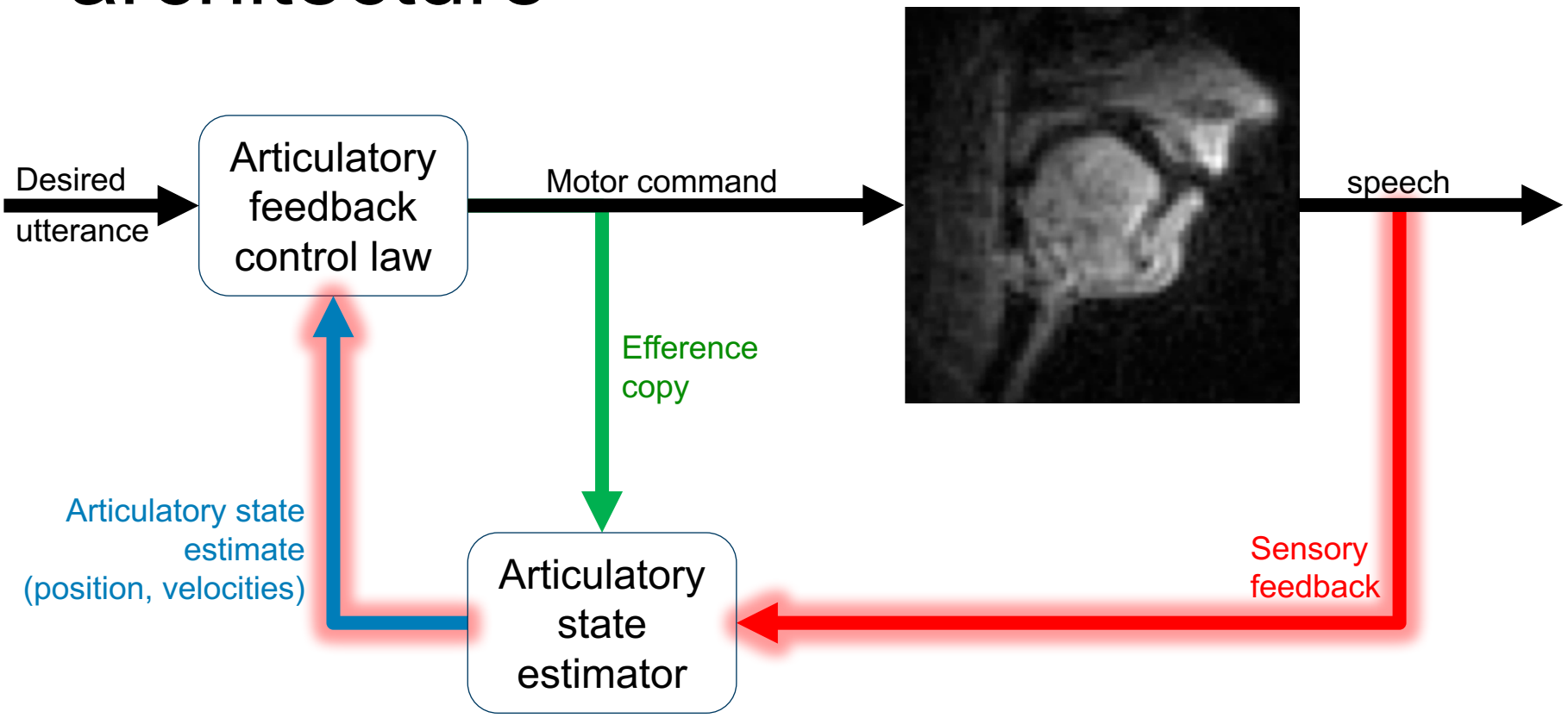

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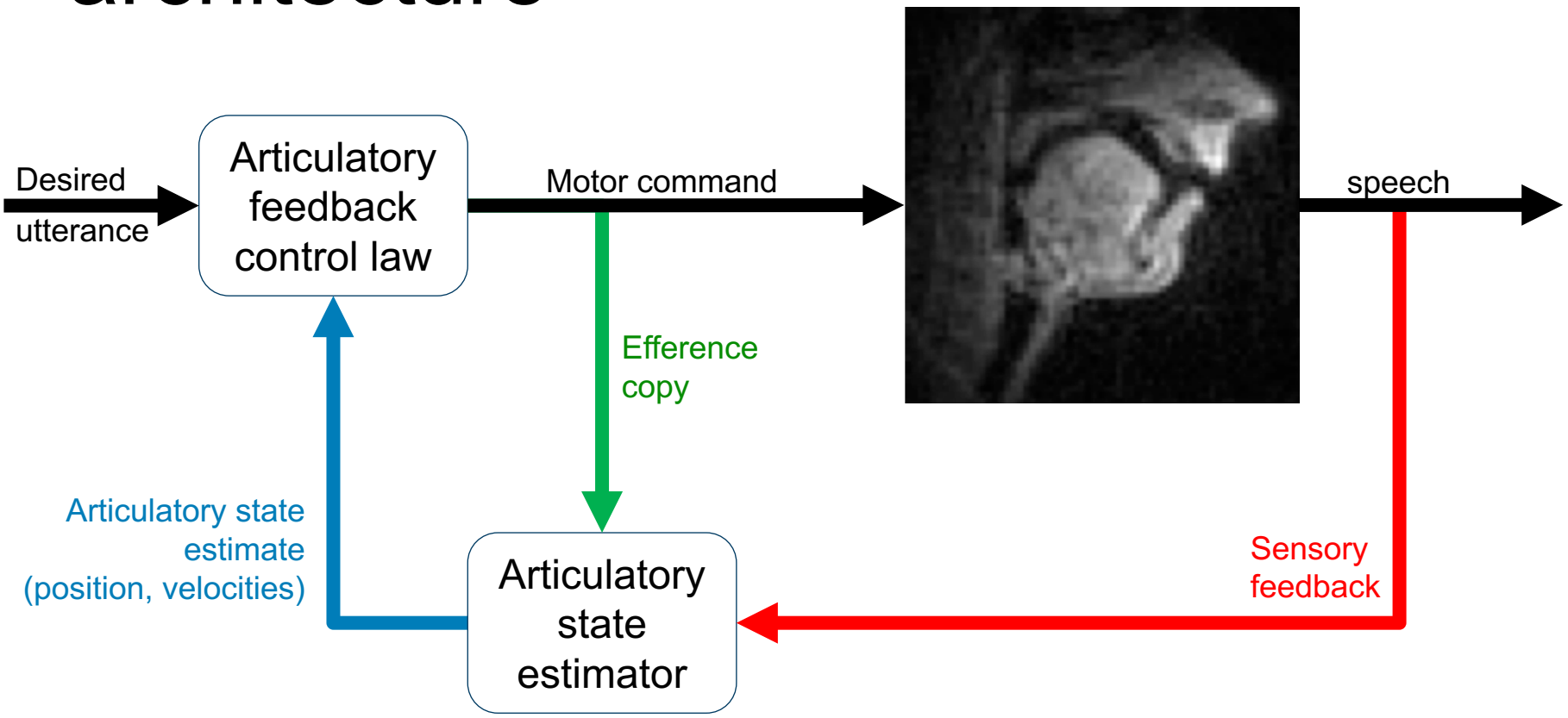

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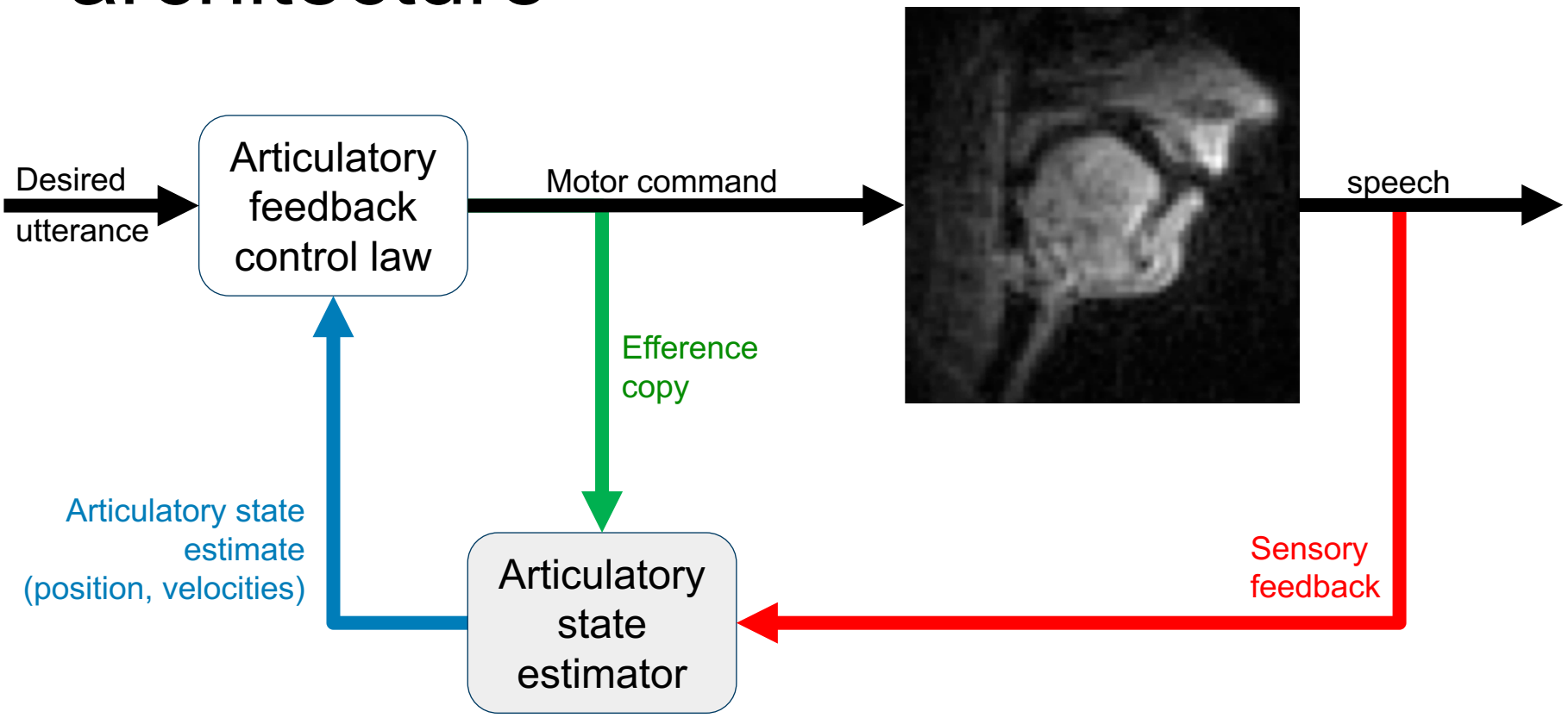
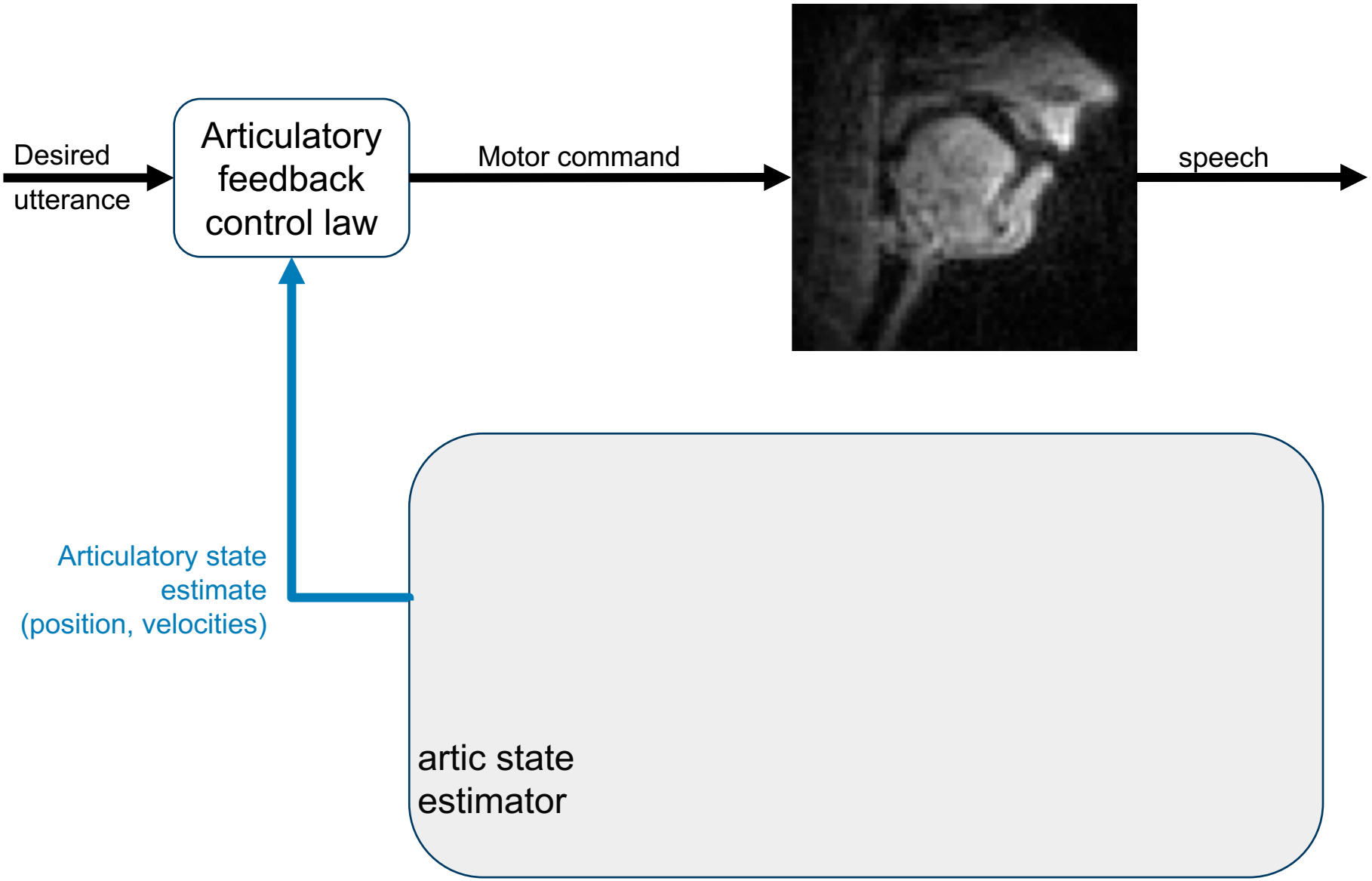


Estimation of the articulatory state



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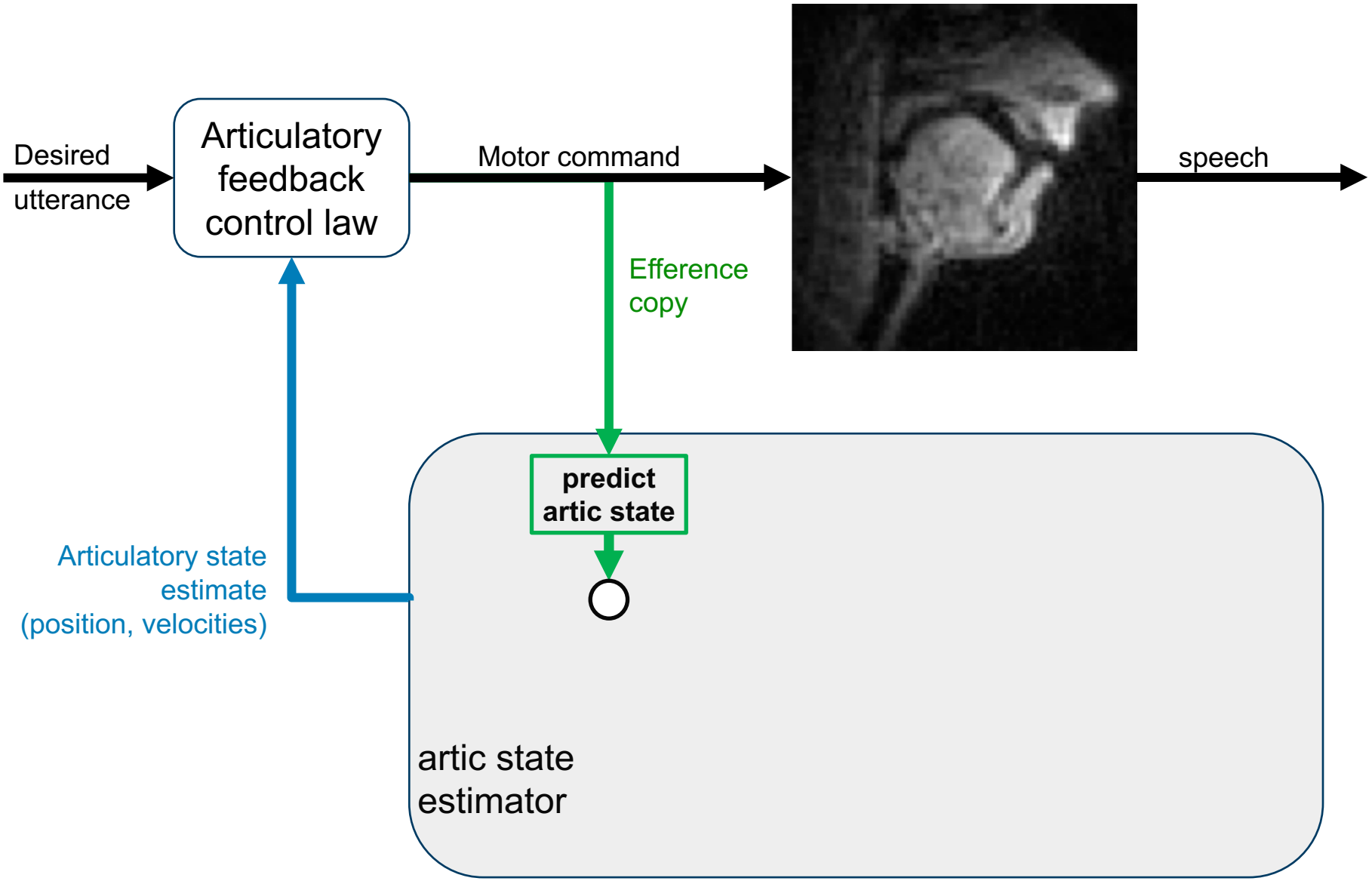

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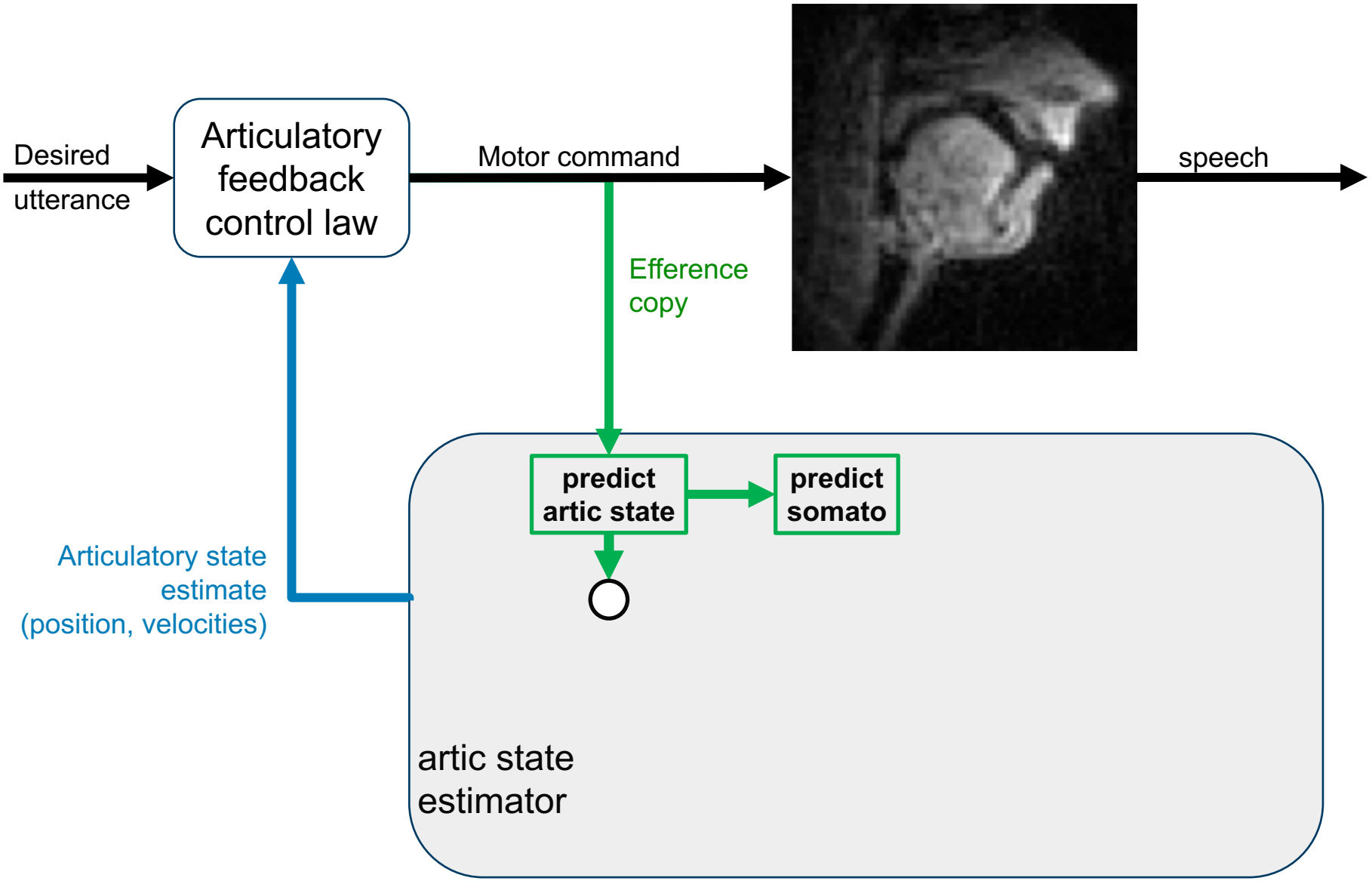

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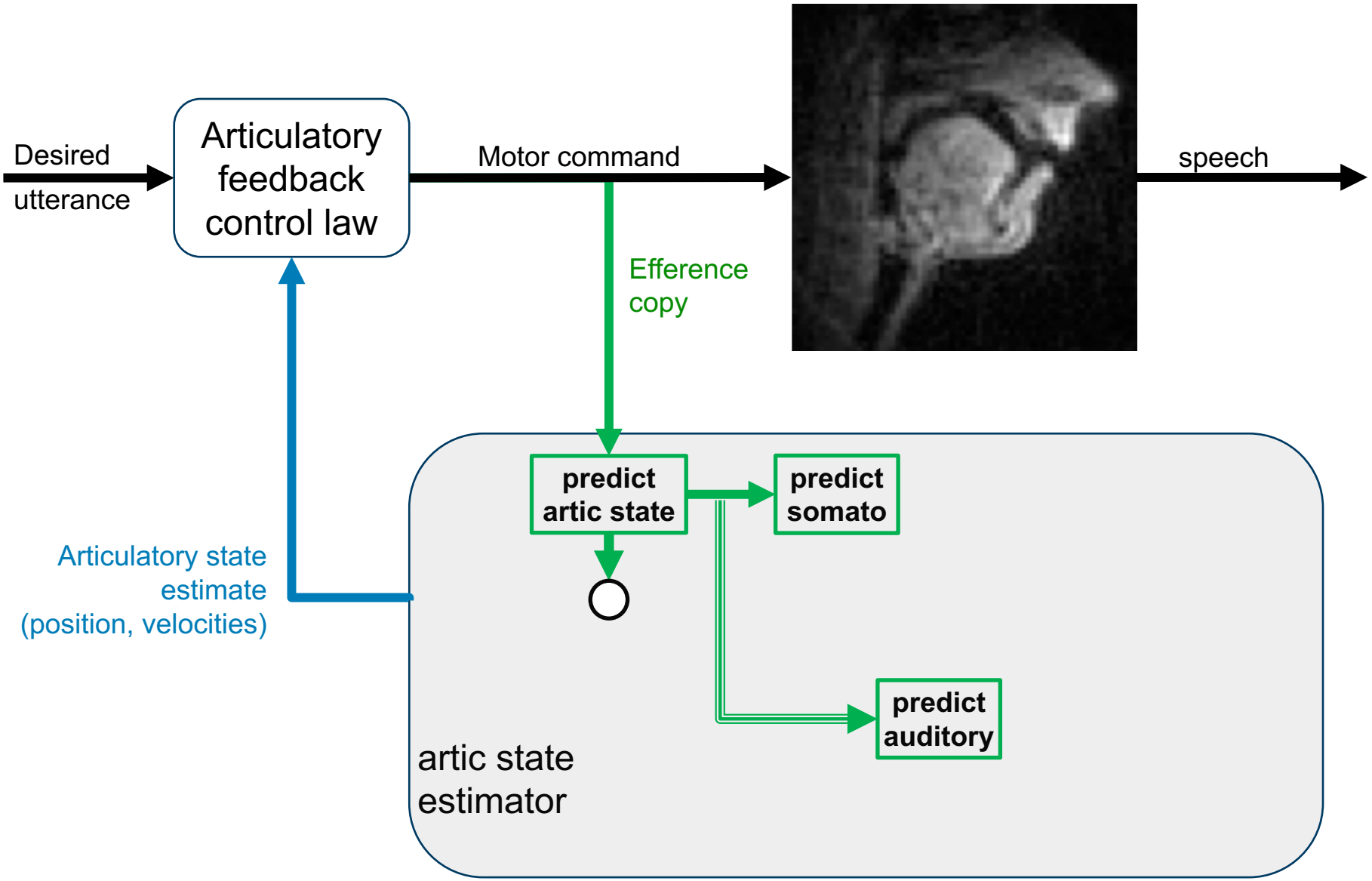

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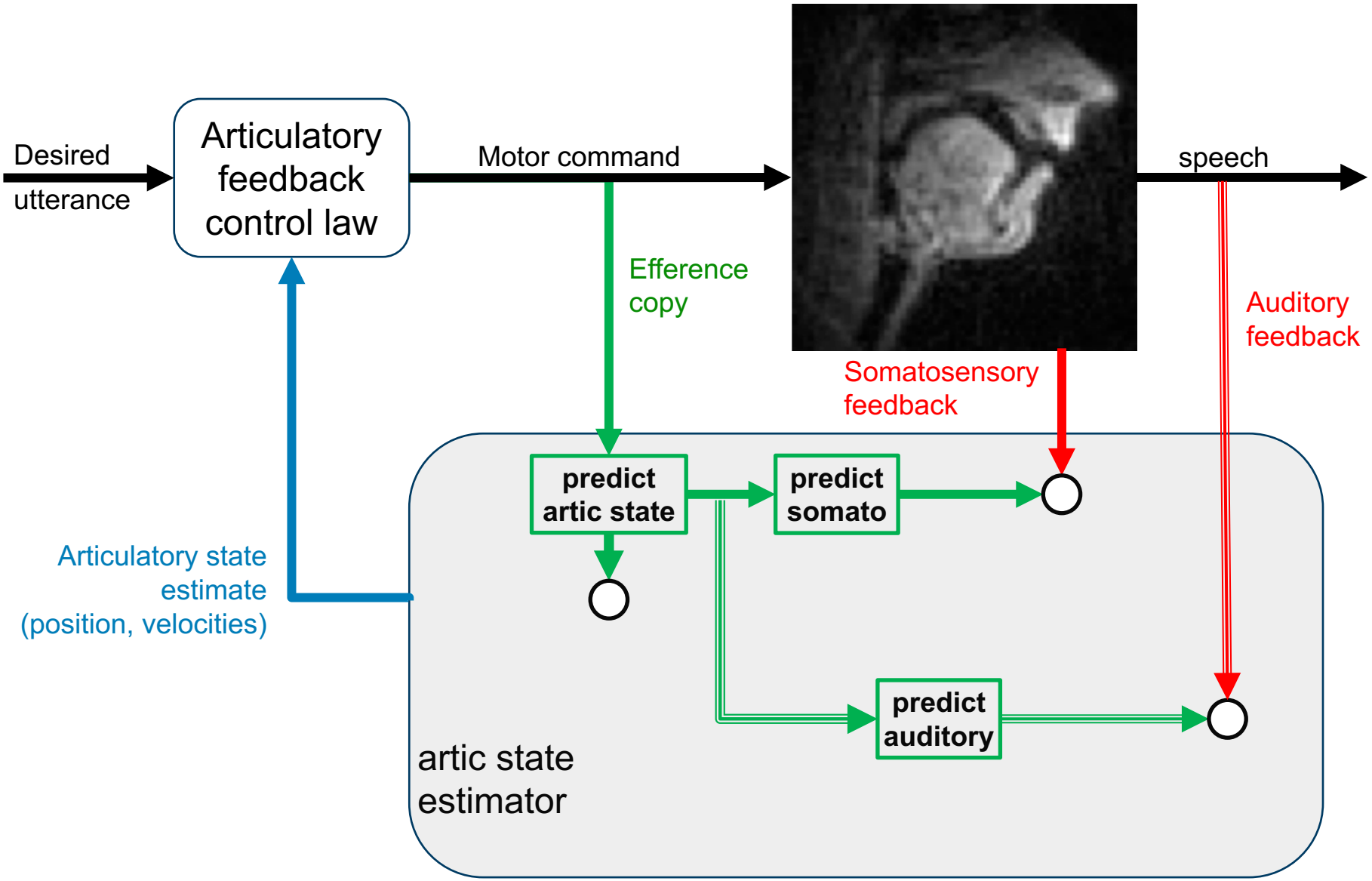

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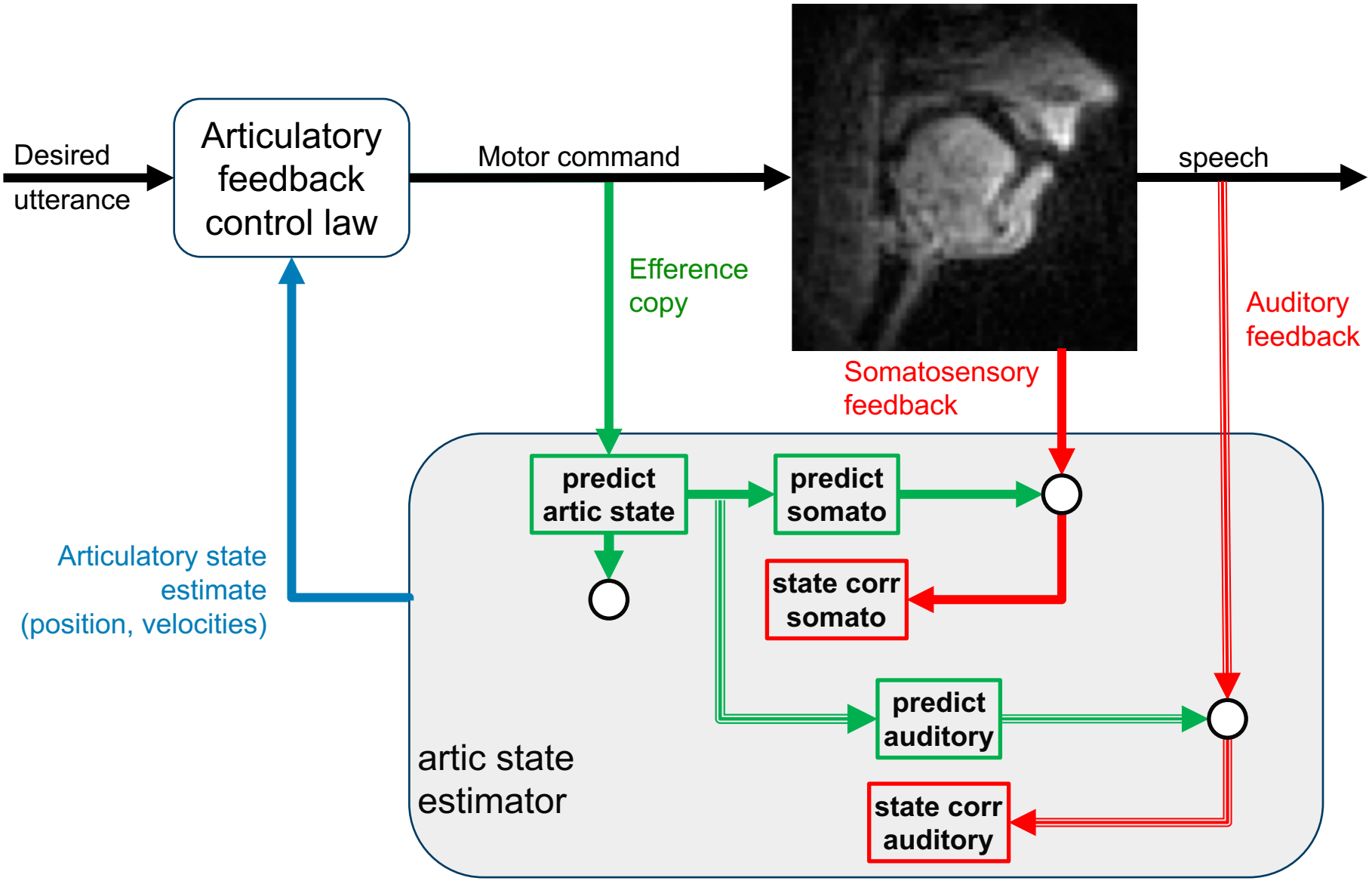

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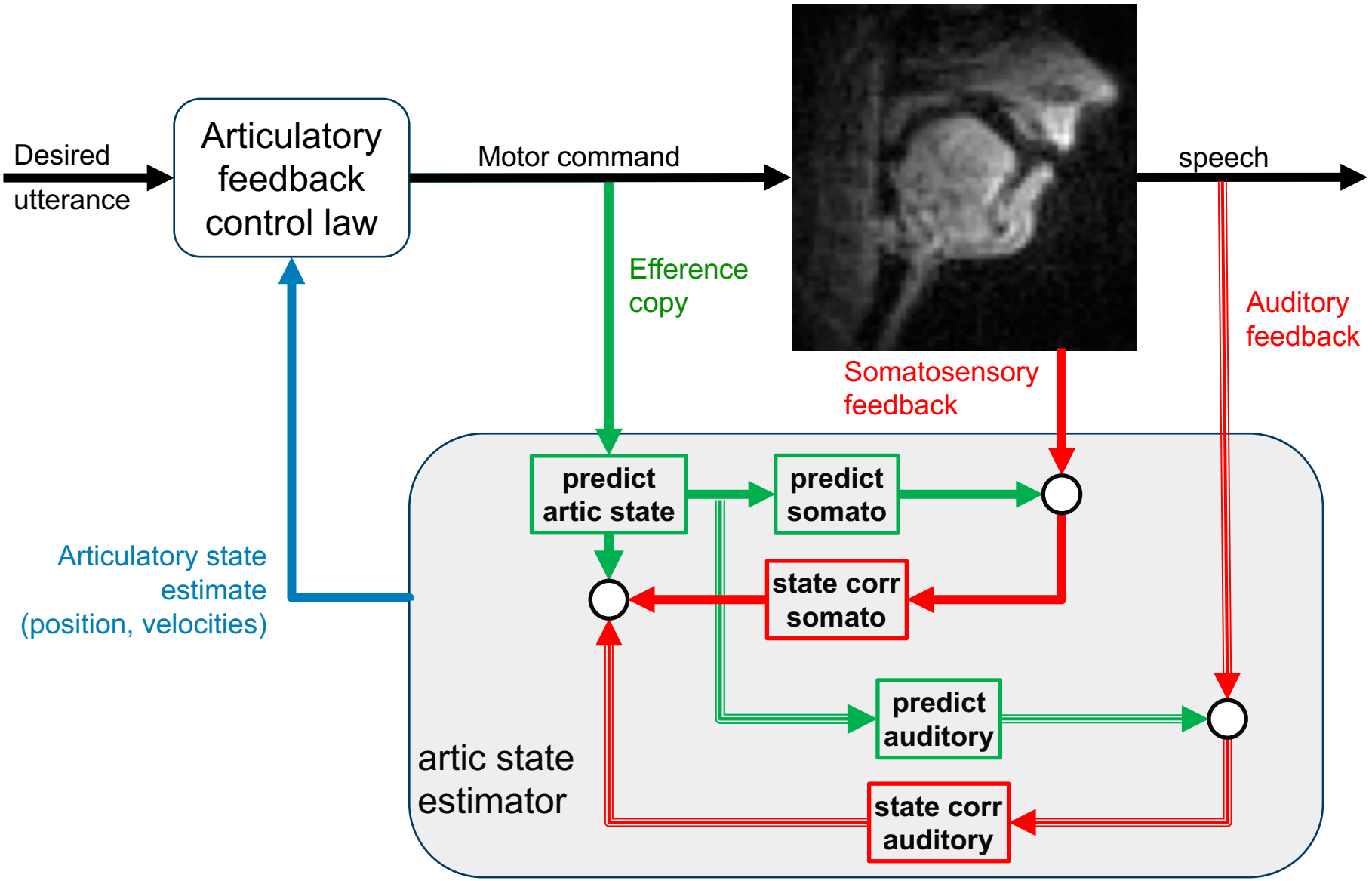

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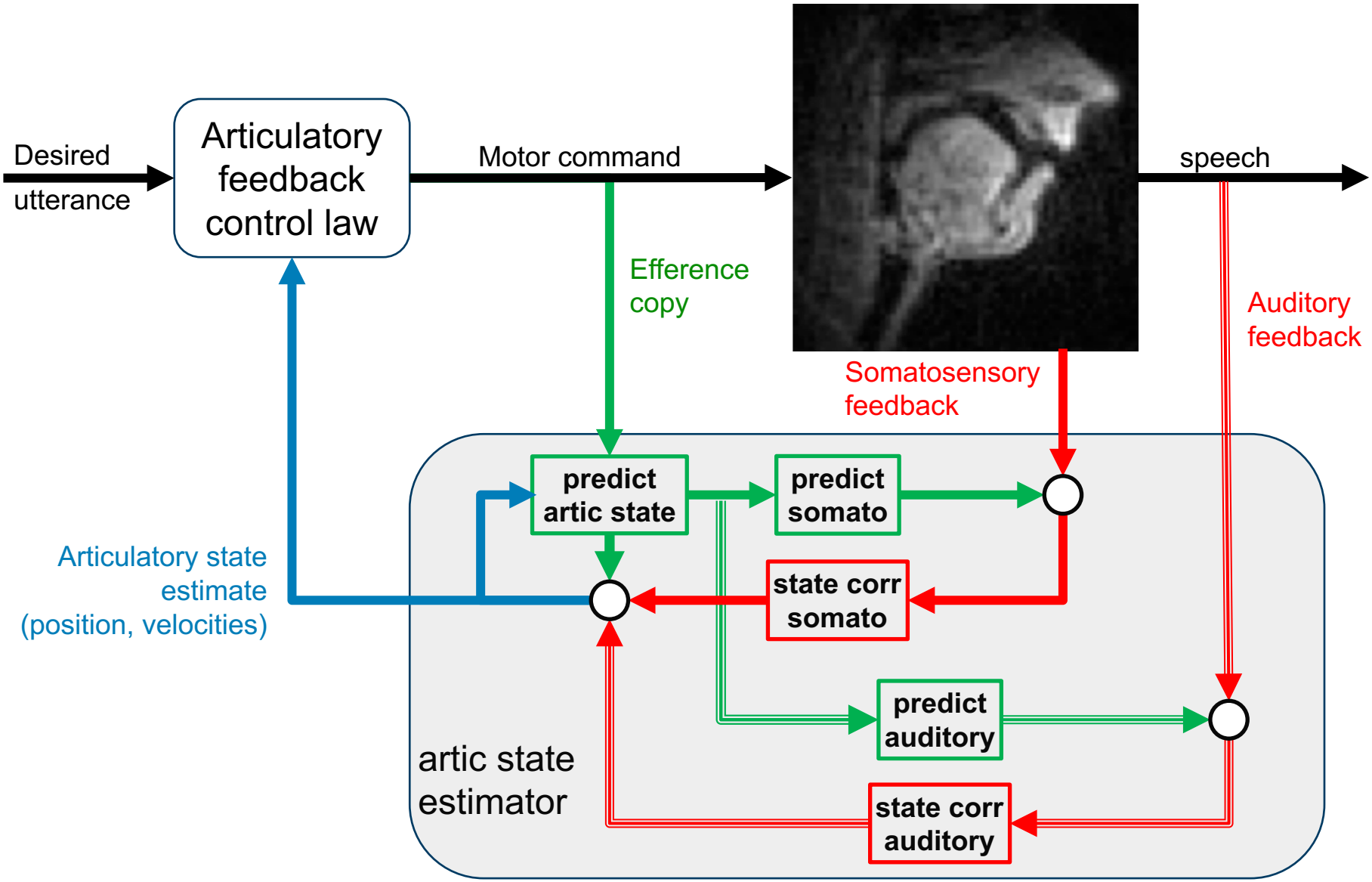
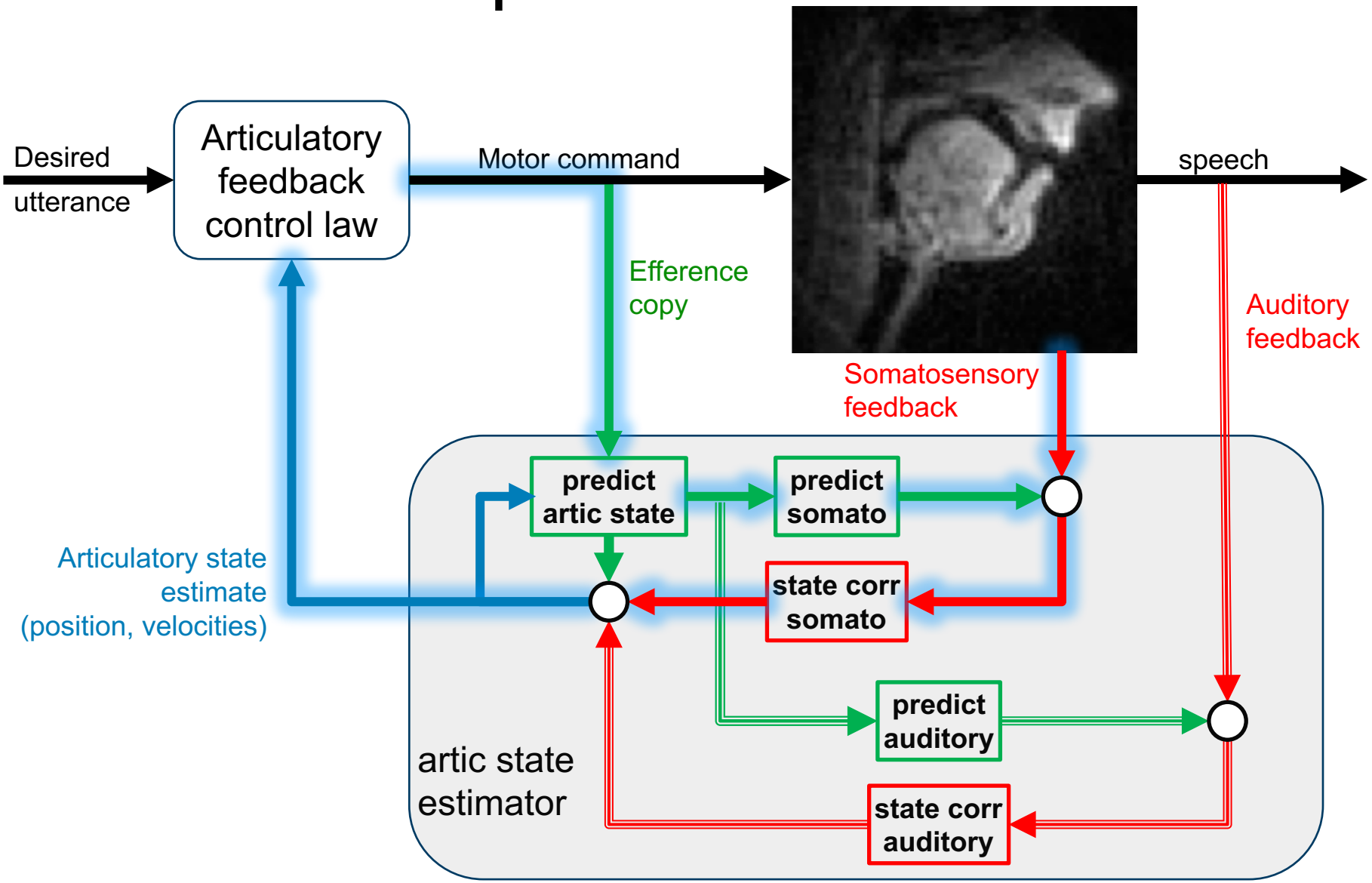
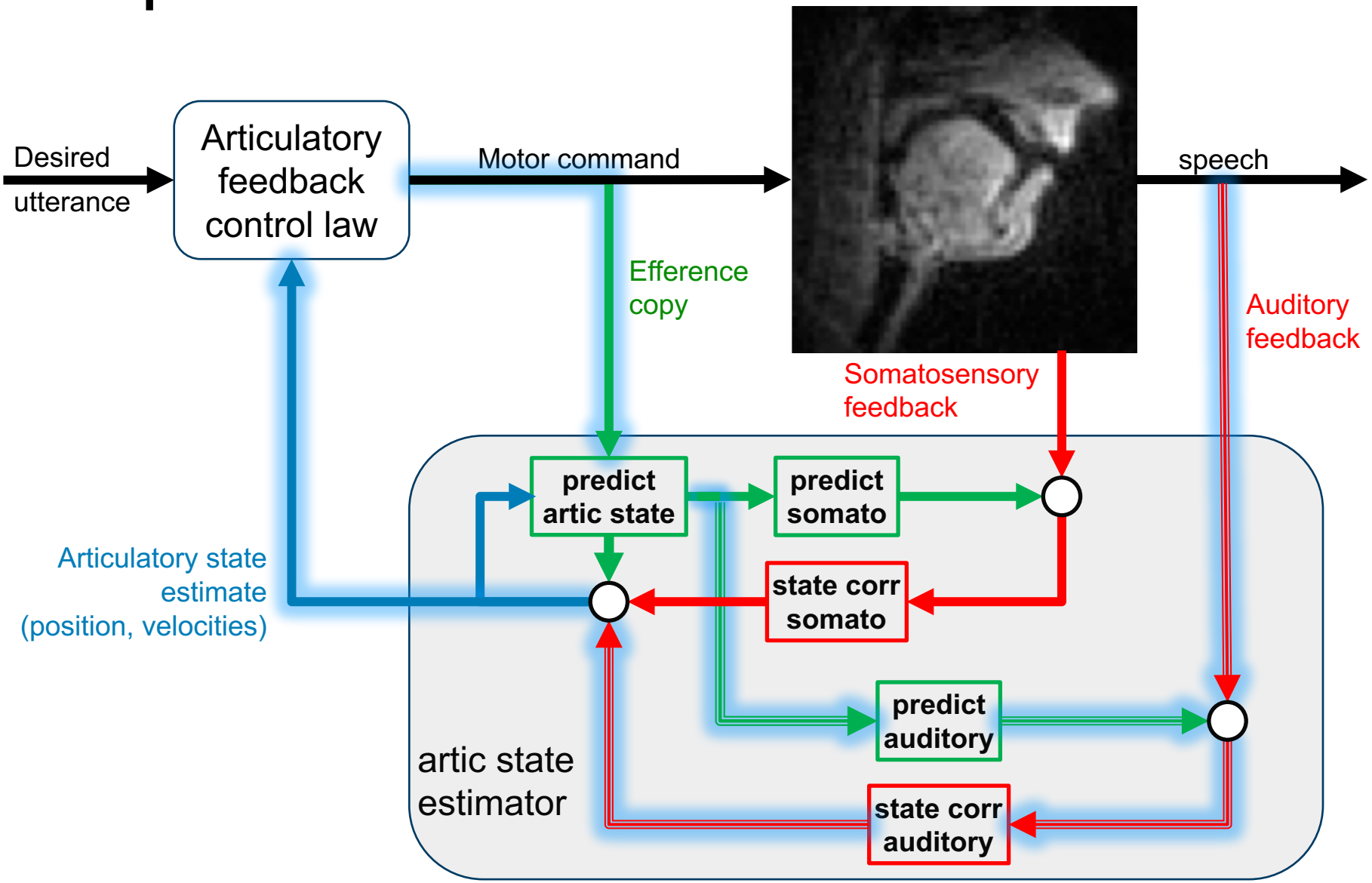


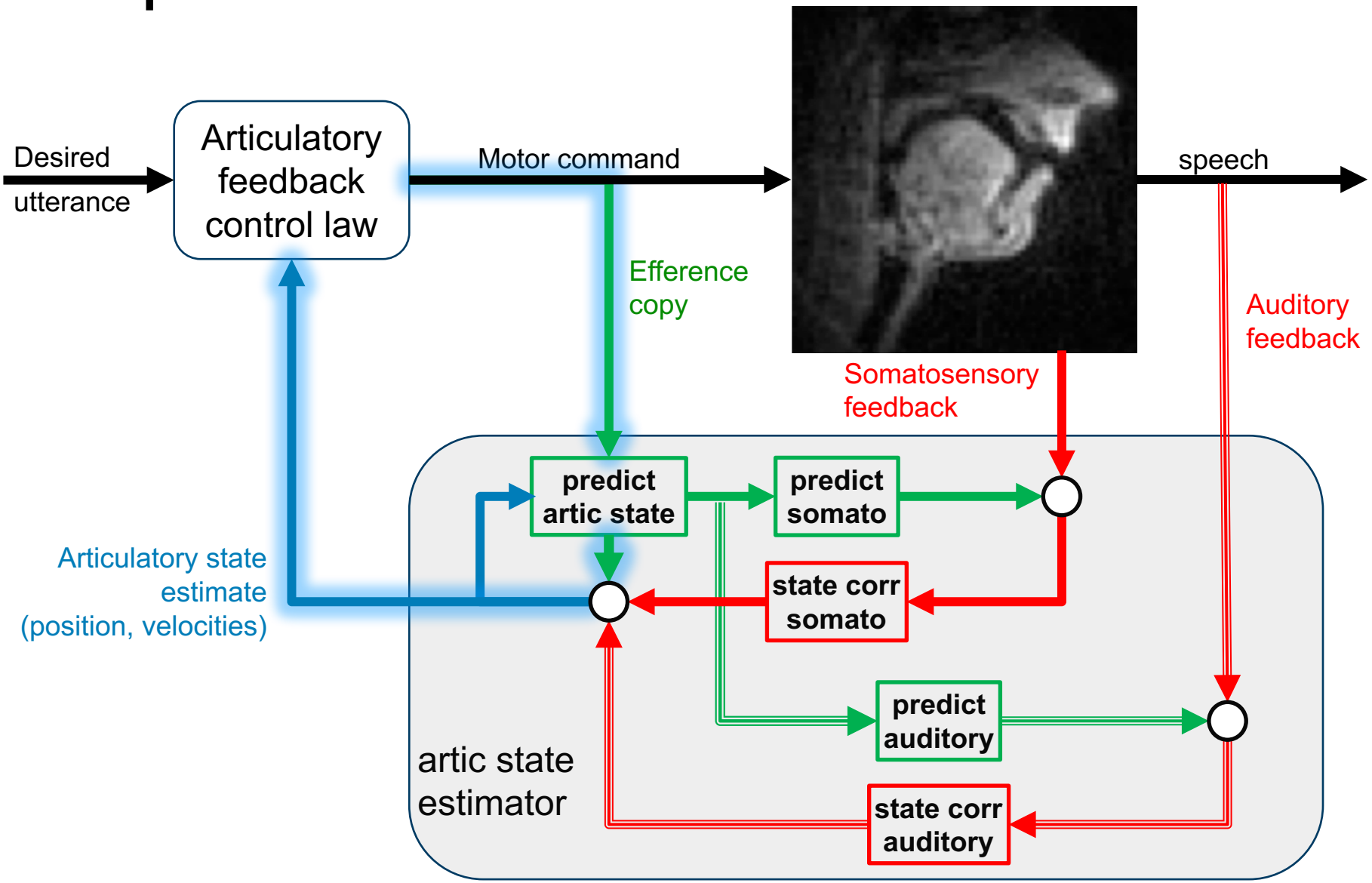
FACTS has a somatosensory feedback loop



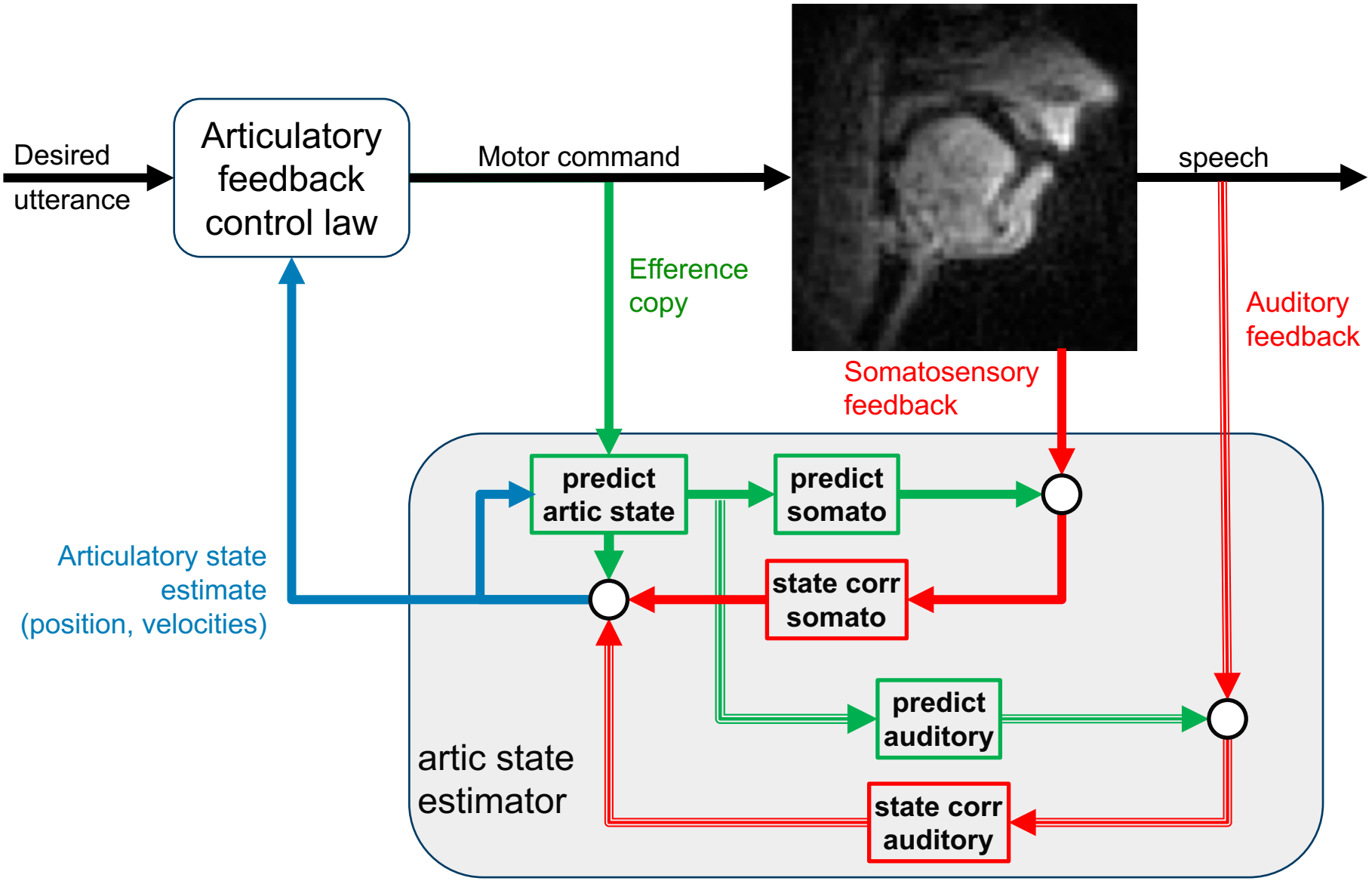
FACTS has an auditory feedback loop



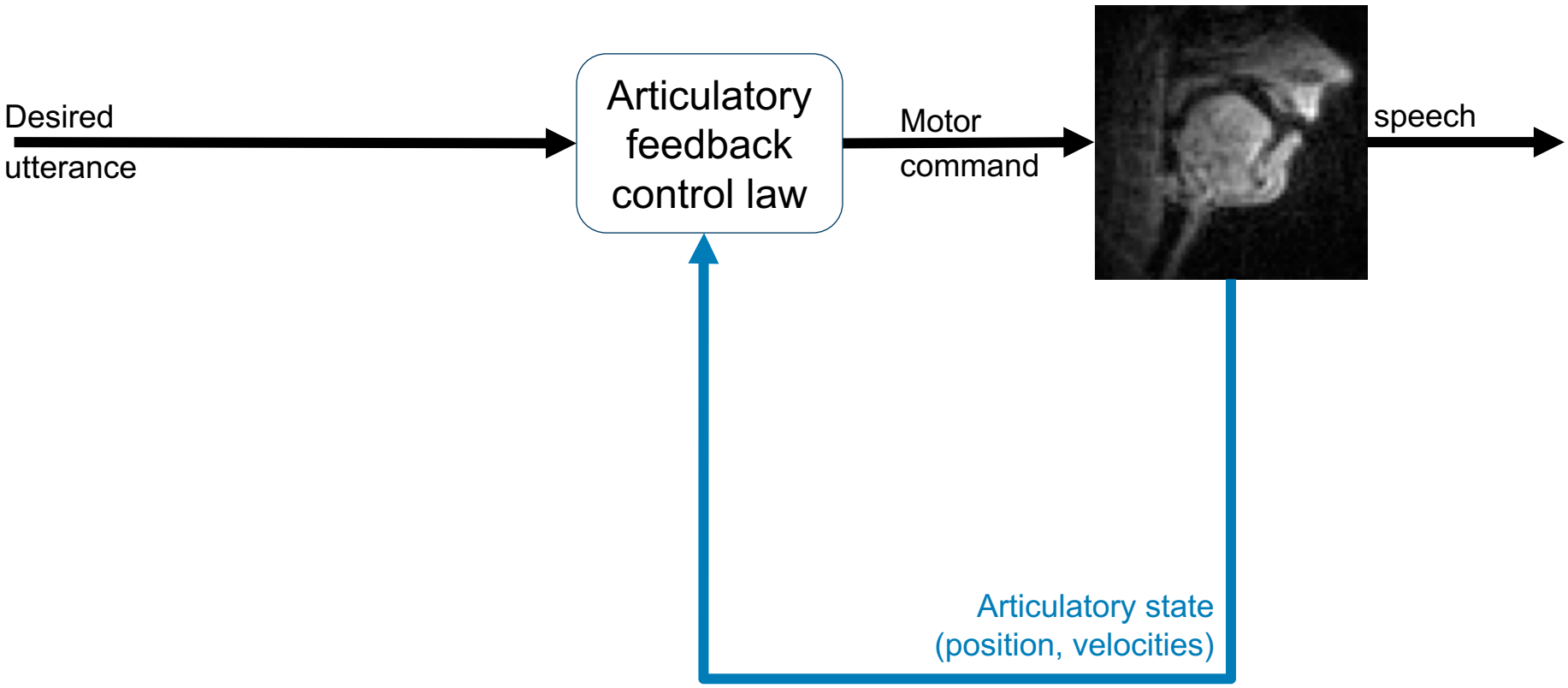
FACTS has a predictive control loop



Modeling control of speech



Moving to a task-level controller



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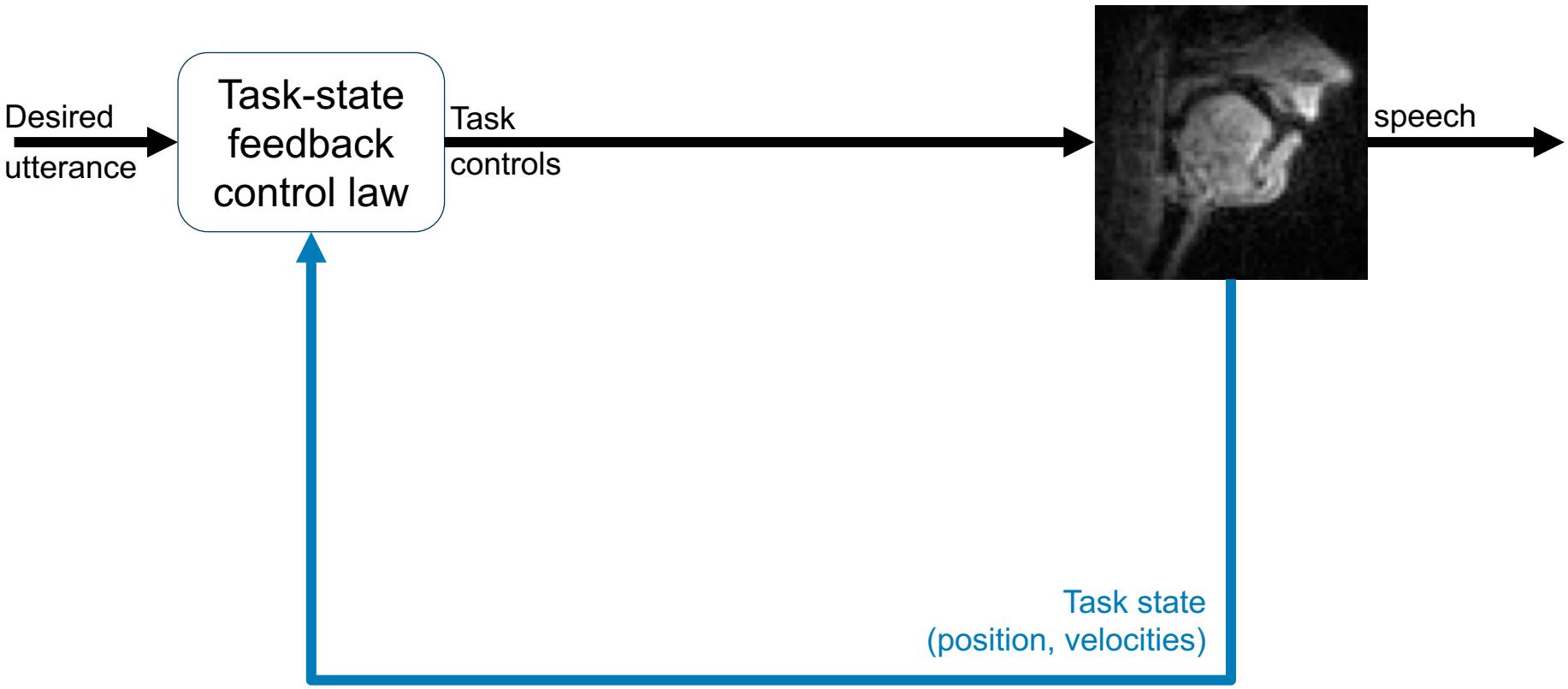


Task Dynamics: a task-state feedback control system

Desired utterance

Task-state feedback control law

"bad"

Lip Aperture — CLO

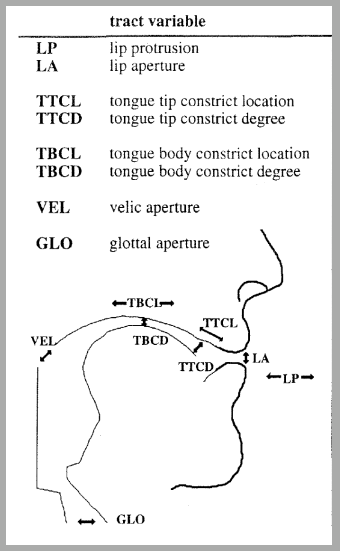
Tongue Tip Constriction Degree — CLO

Tongue Body Constriction Degree — WIDE

(pos

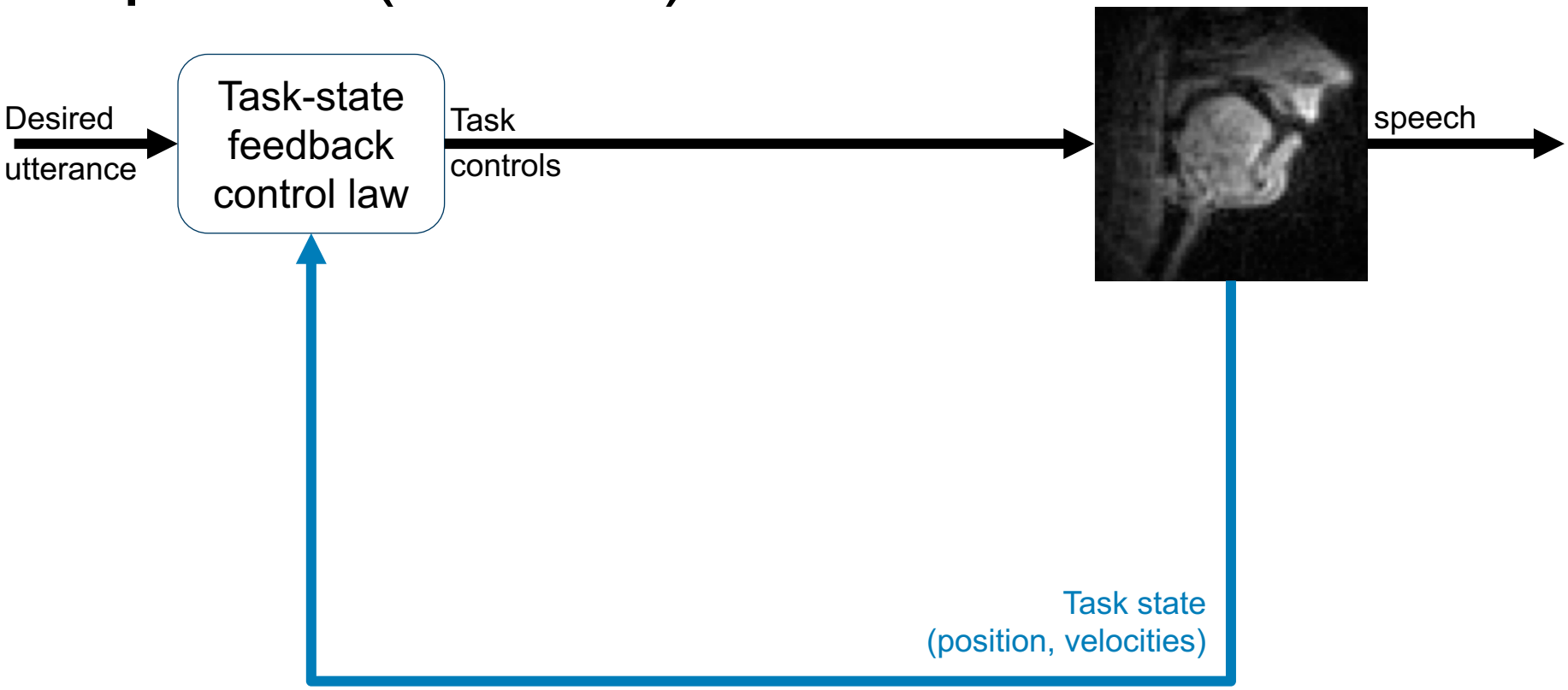
speech

Tasks: constrictions in the vocal tract



Saltzman & Munhall. (1989): *Ecological Psychology, 1*(4), 333-382.

Feedback-Aware Control of Tasks in Speech (FACTS) model



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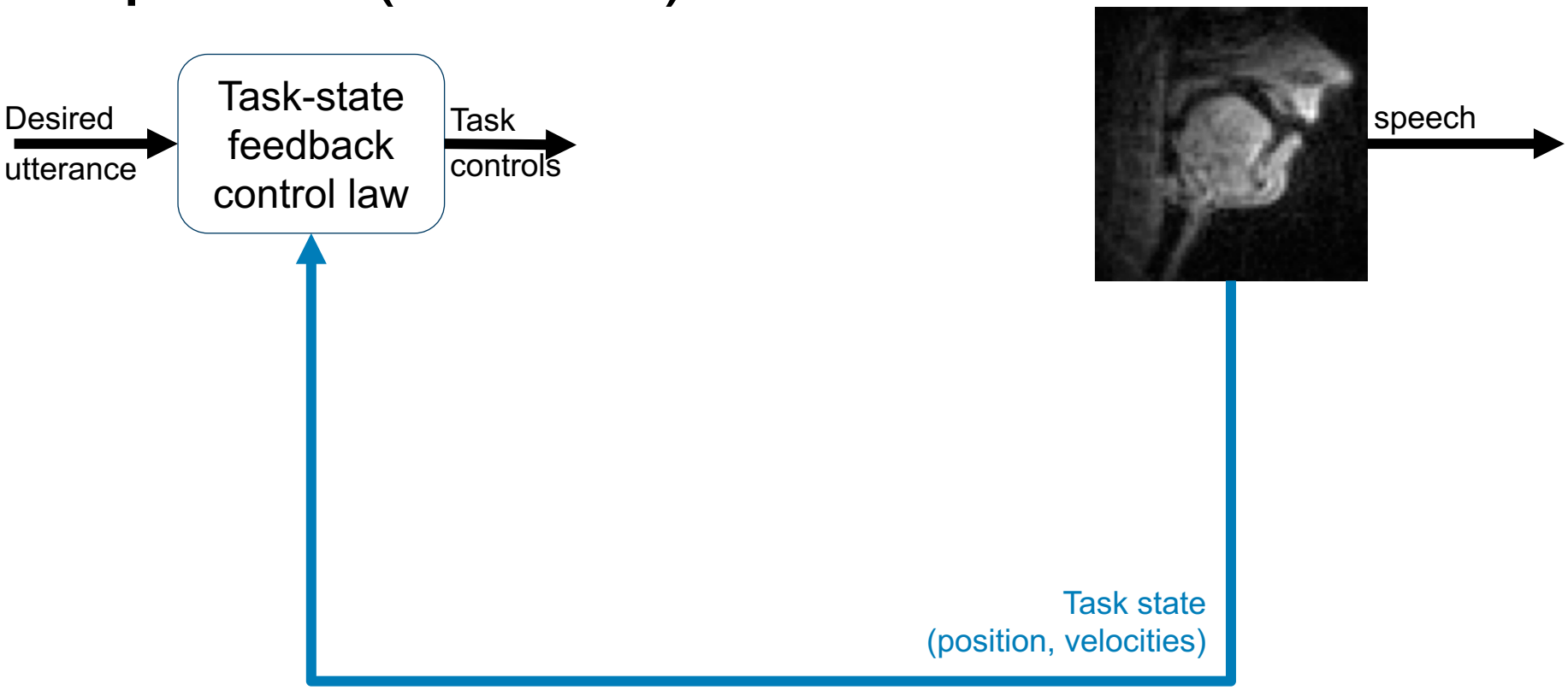

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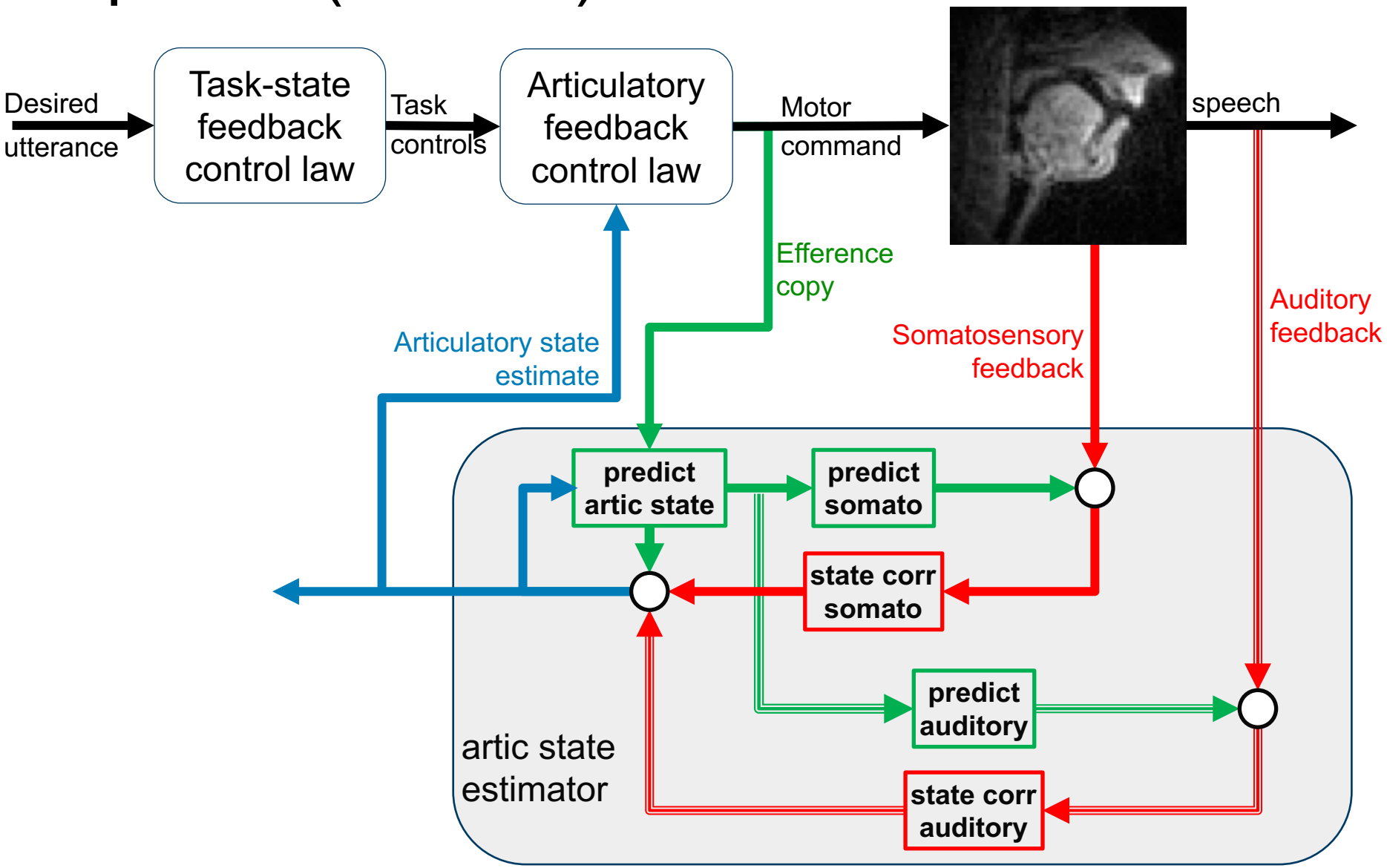

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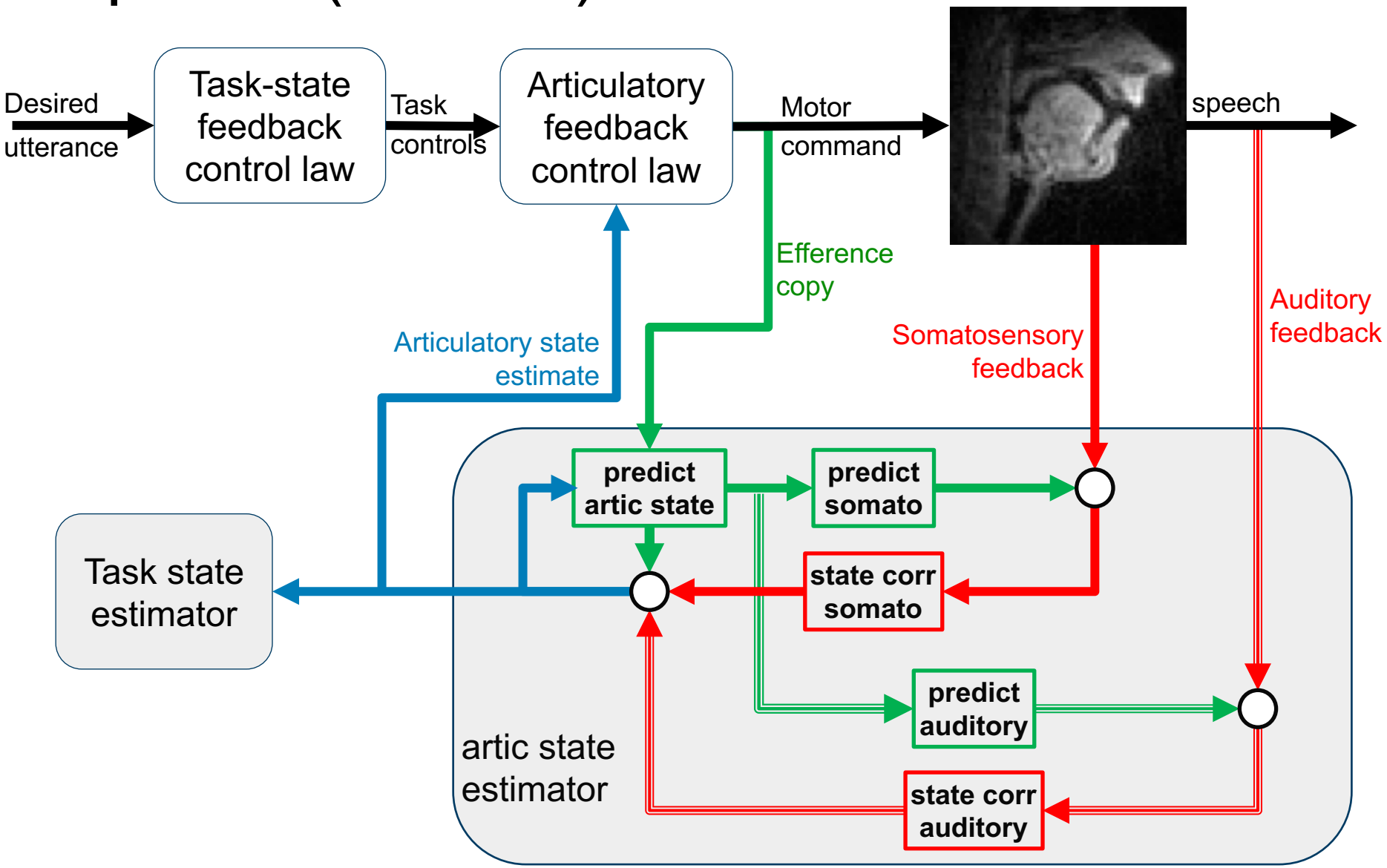

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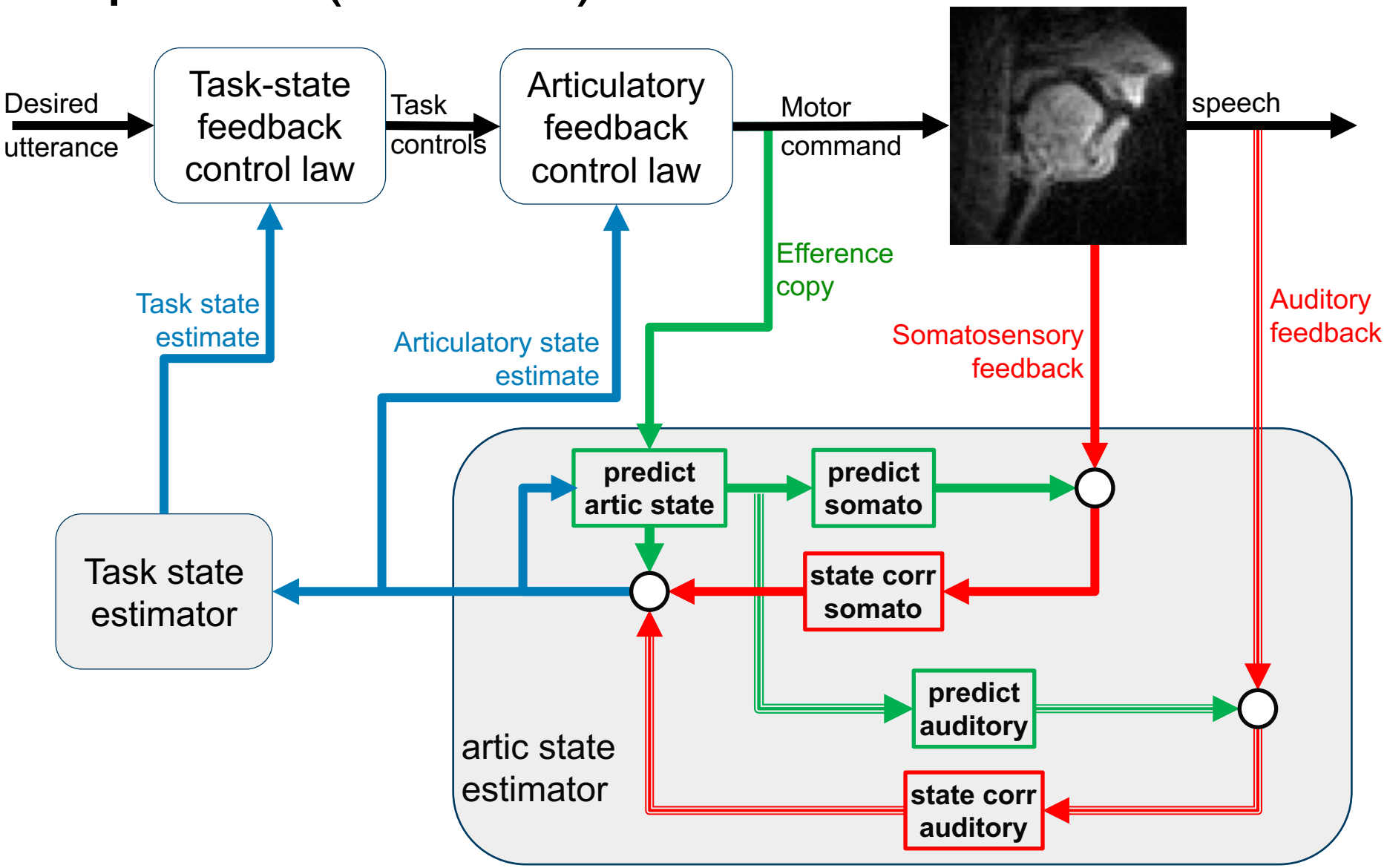
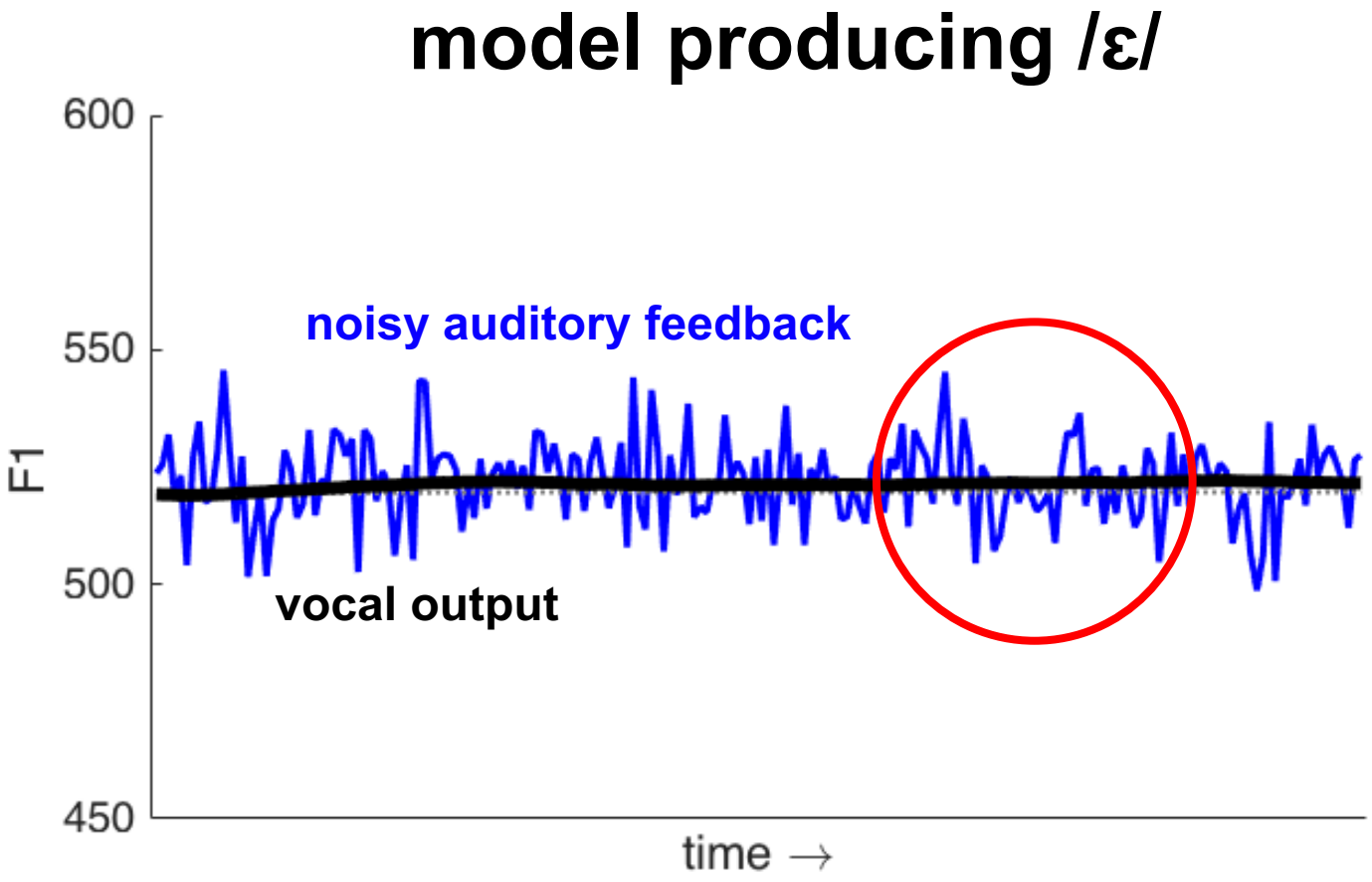
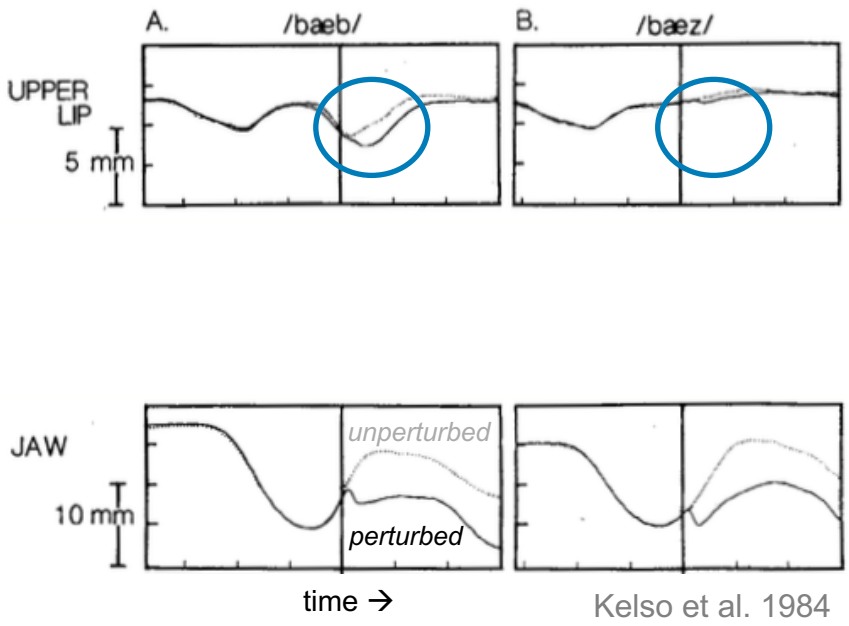


FACTS produces stable speech in the presence of sensory noise



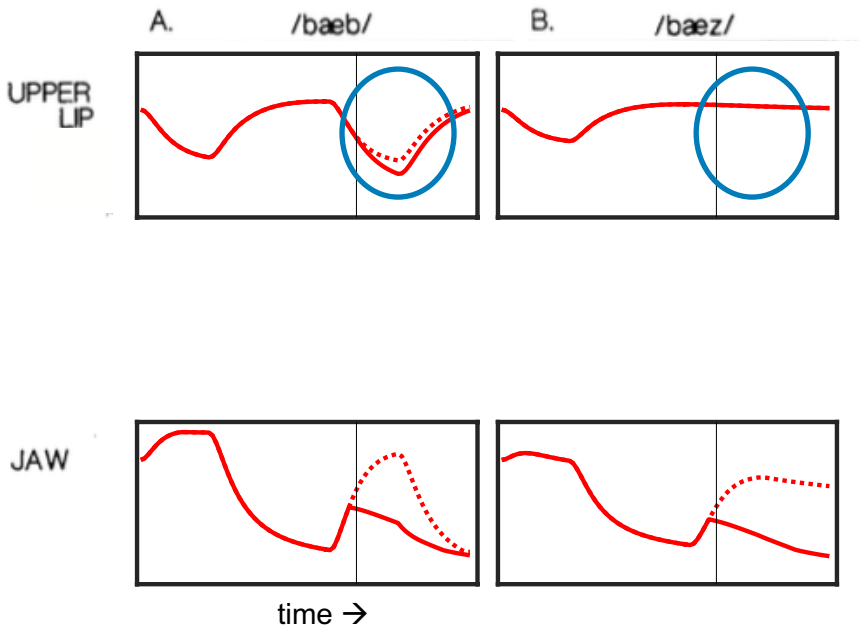
FACTS simulates task-specific responses to mechanical perturbations

Human data

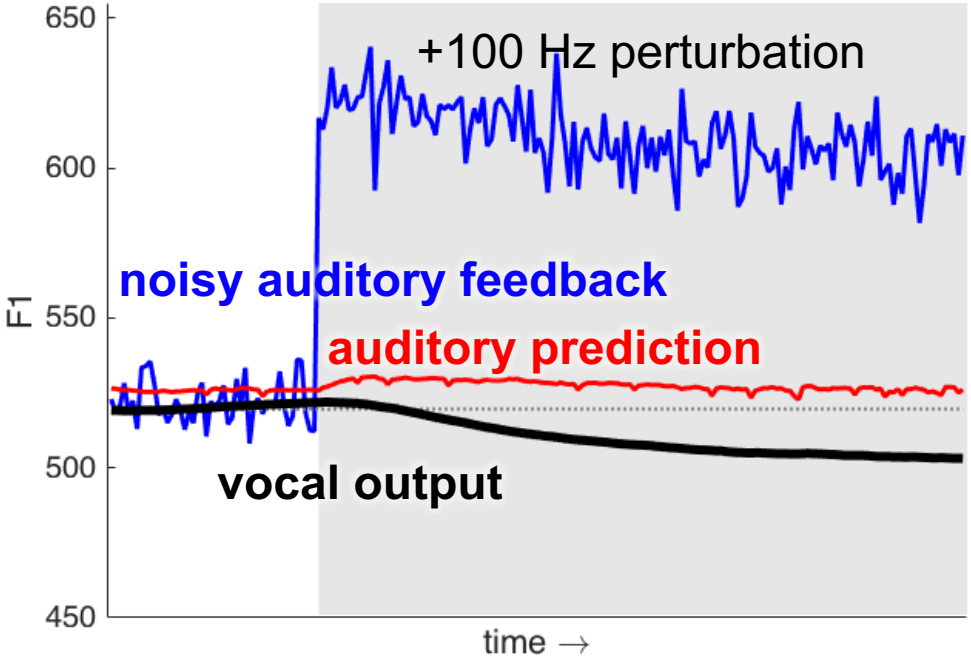


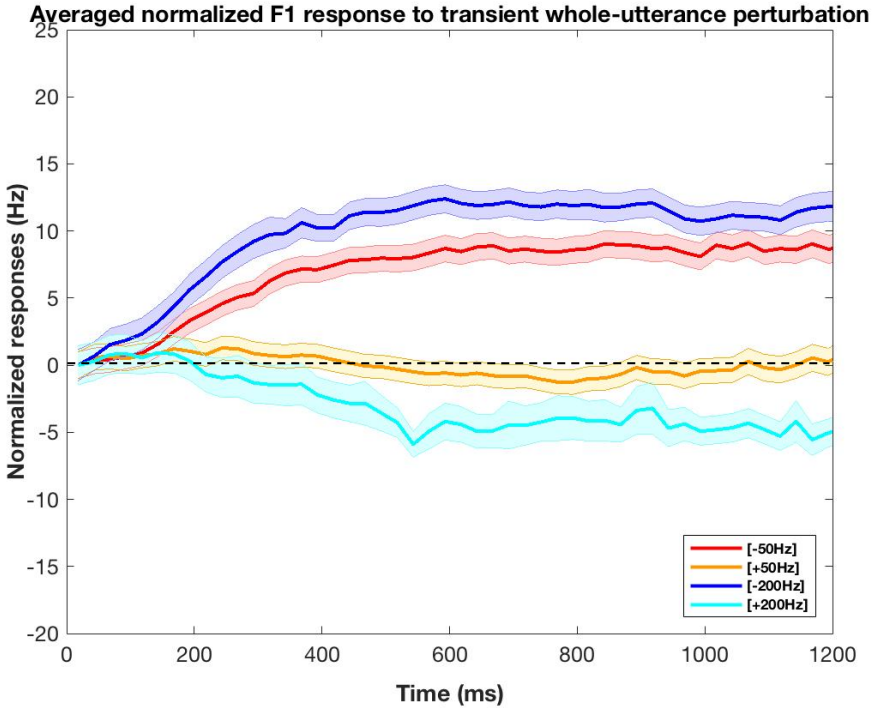
Kelso et al. 1984

Model data

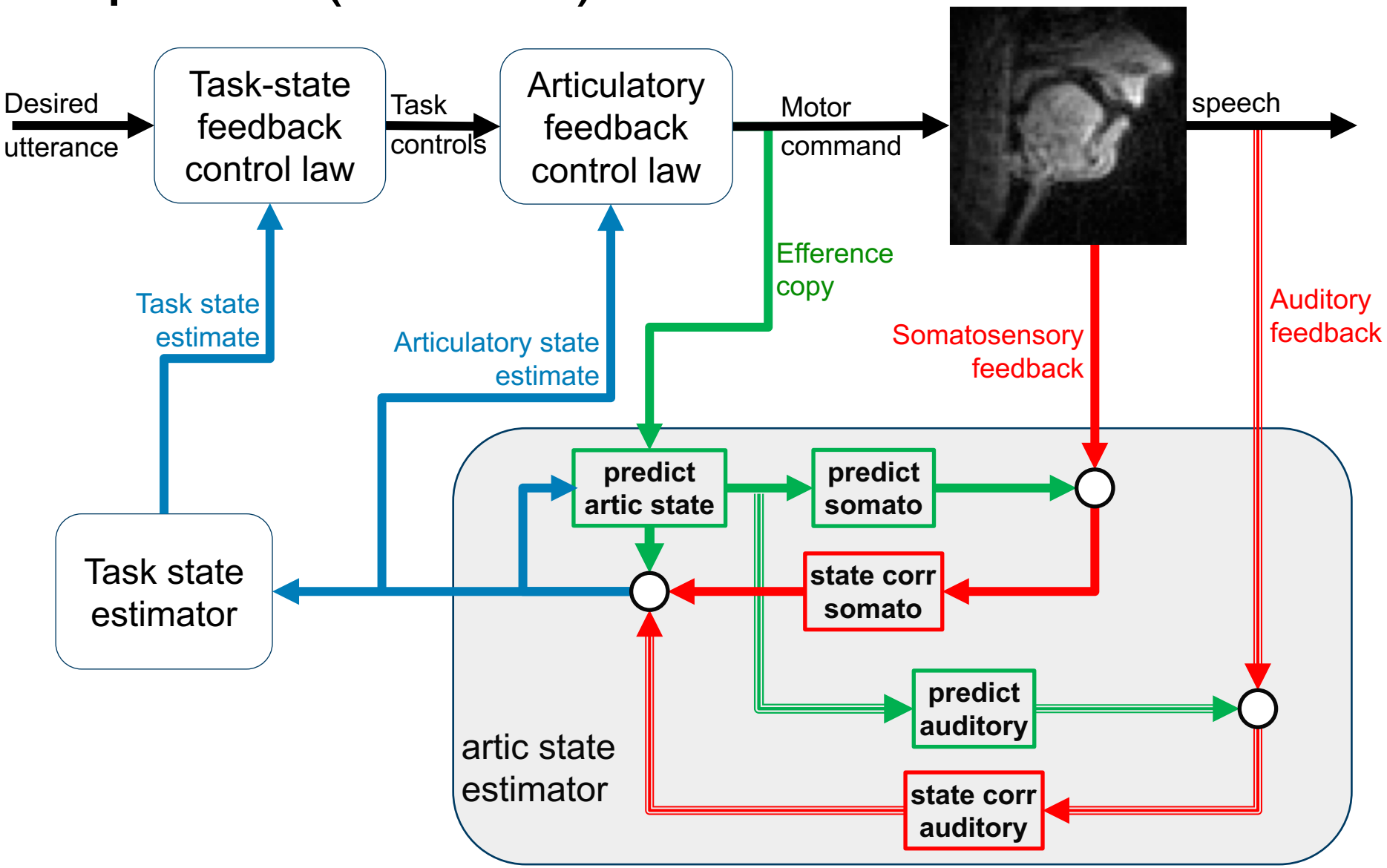


FACTS simulates partial compensation for auditory perturbations





Feedback-aware Control of Tasks in Speech (FACTS) model



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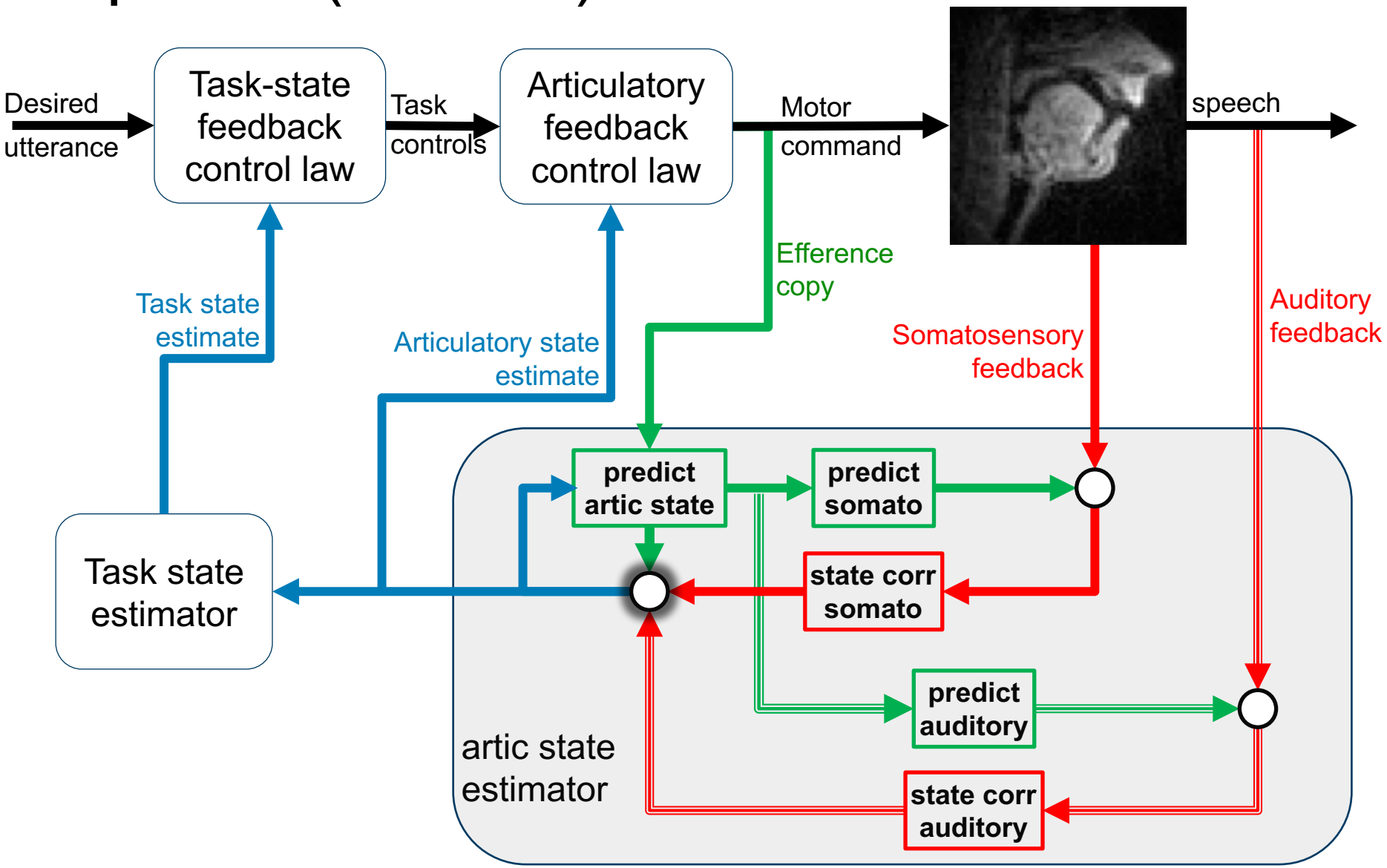

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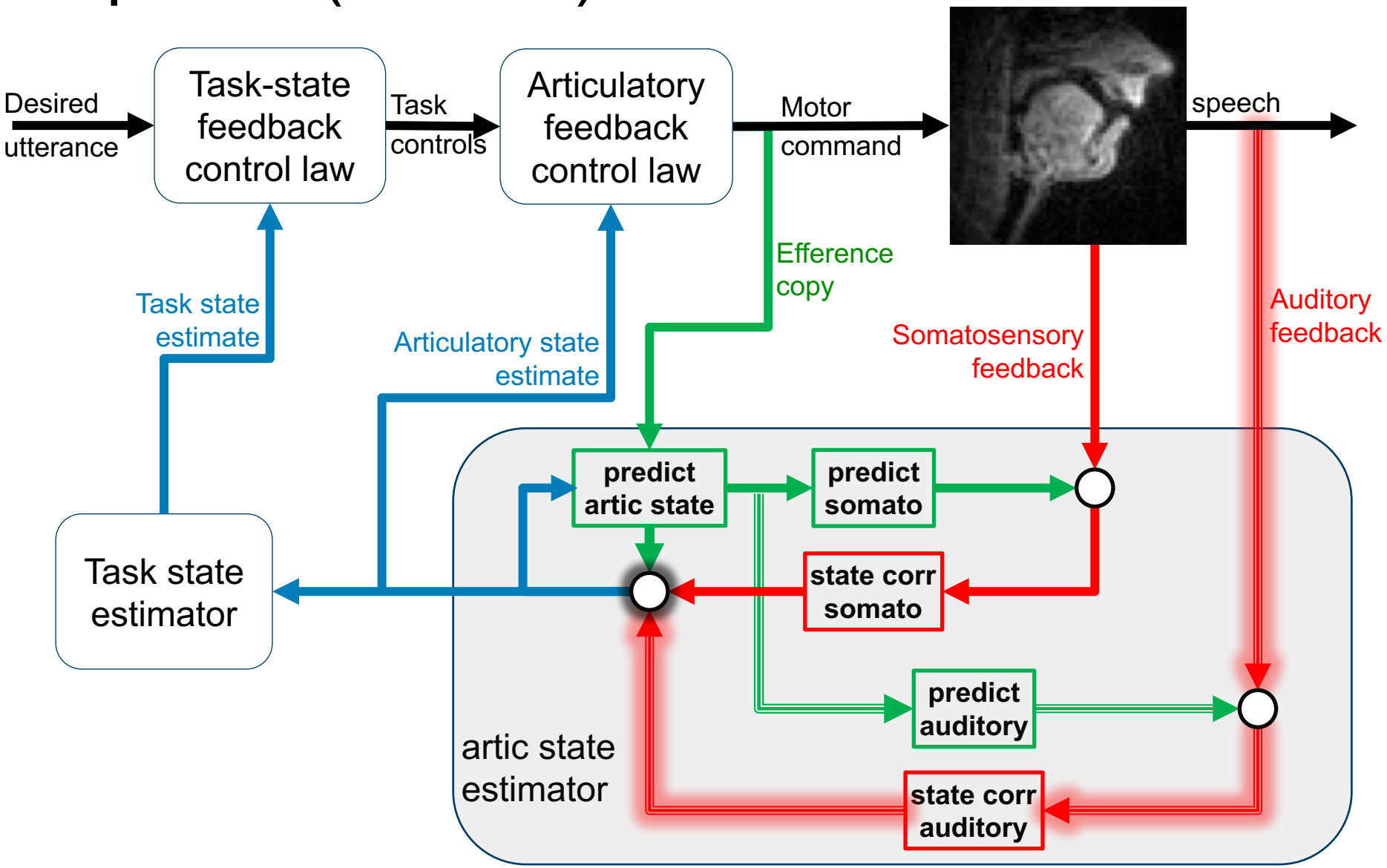

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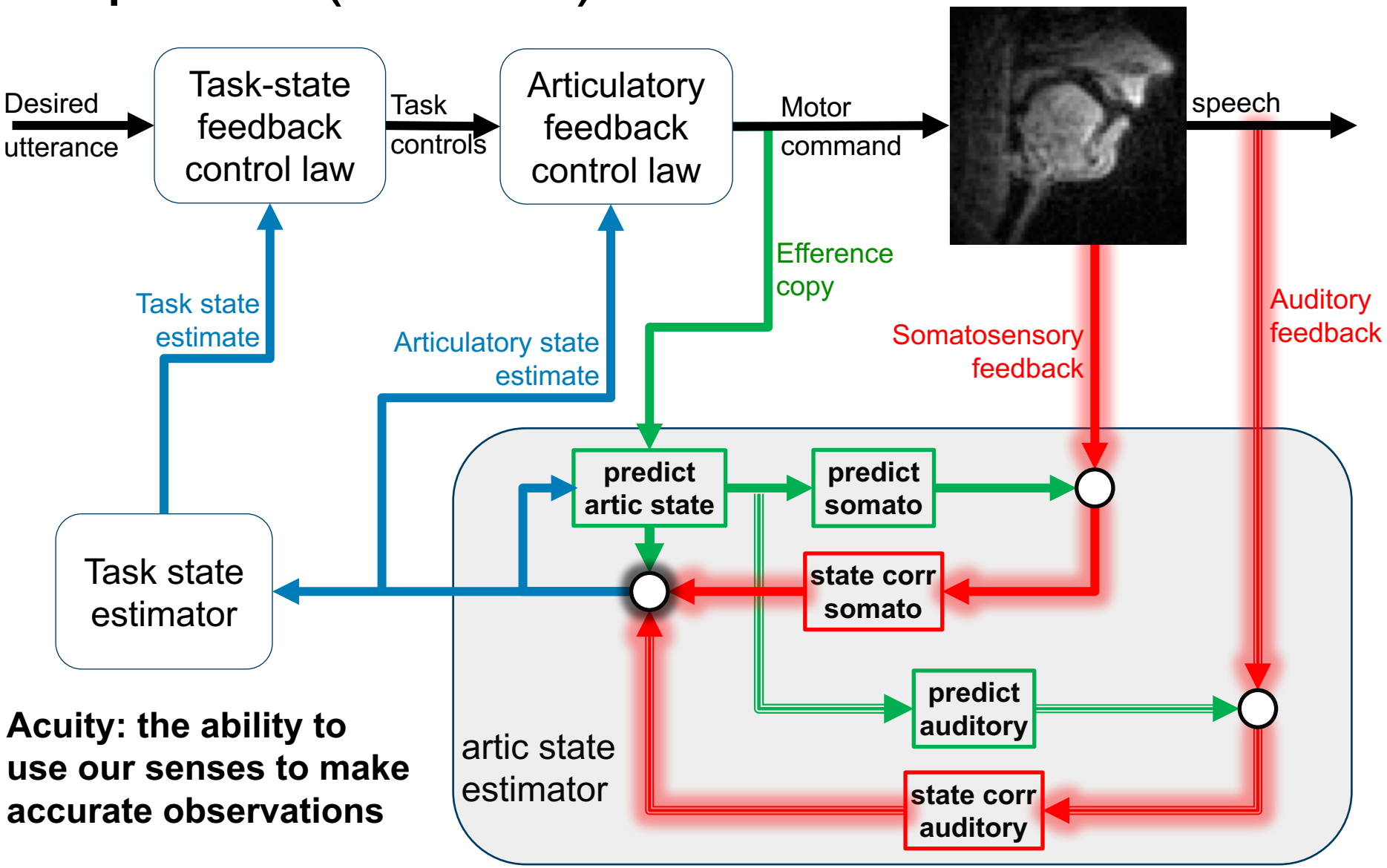
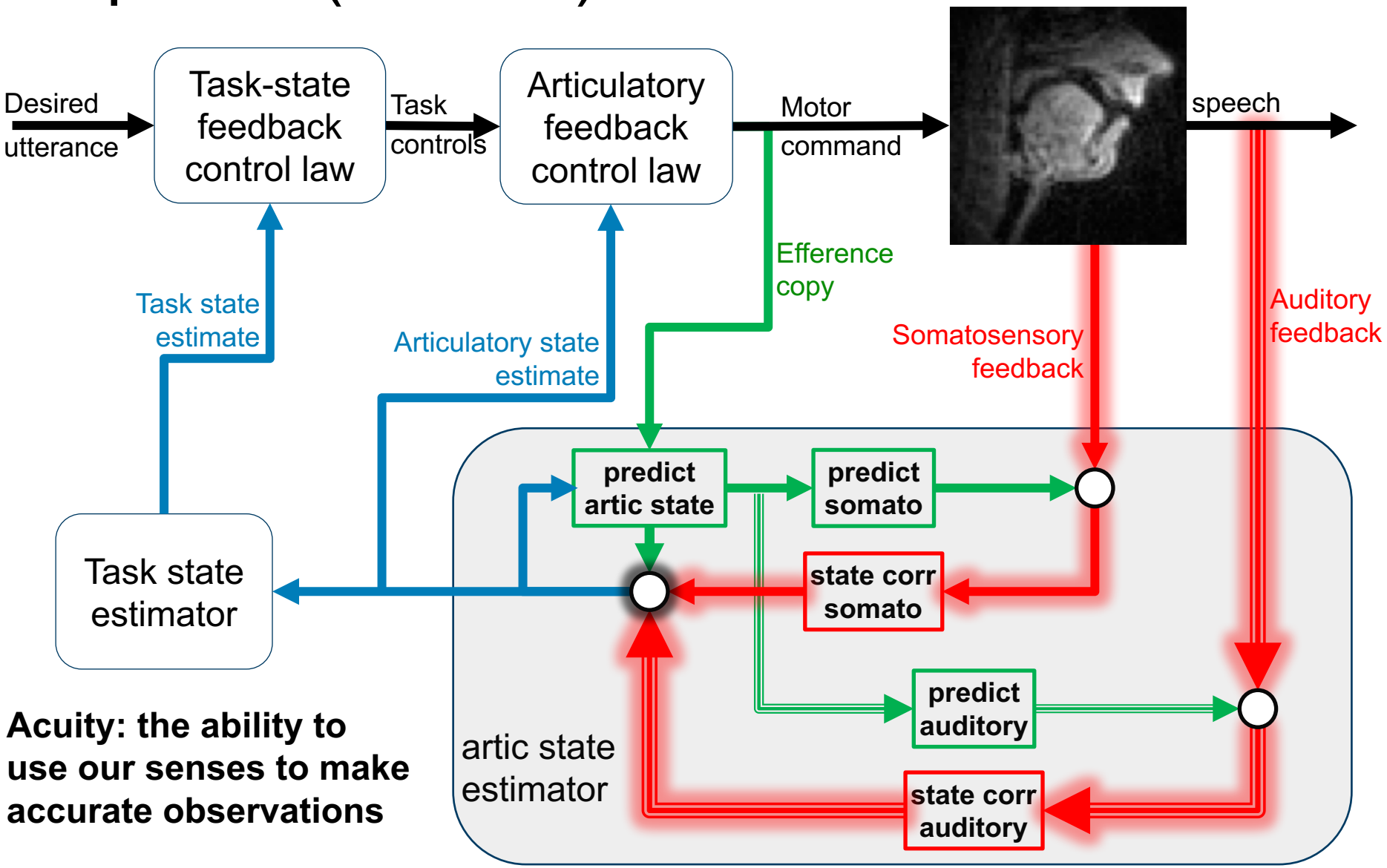


Acuity: the ability to use our senses to make accurate observations

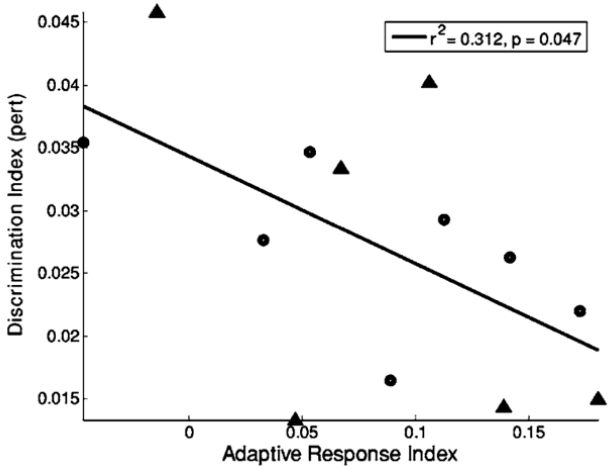
Feedback-aware Control of Tasks in Speech (FACTS) model



Acuity: the ability to use our senses to make accurate observations

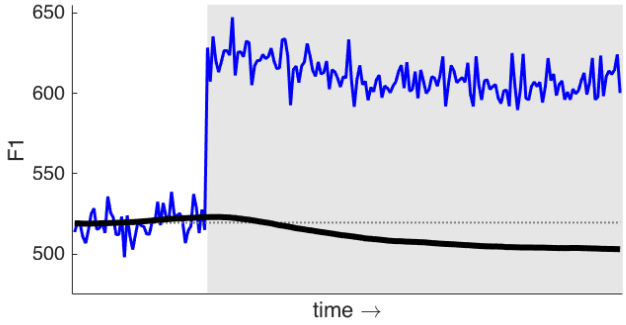
Some evidence for acuity-response relationship

Speakers with better auditory acuity adapt more to auditory perturbations

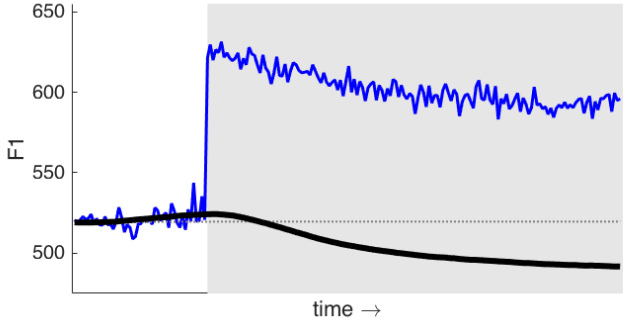


Villacorta et al. 2007

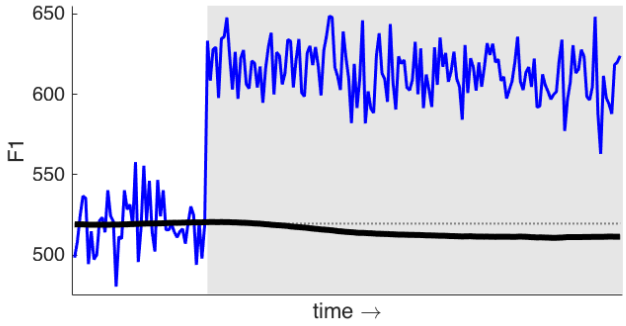
Baseline response



⇧ **auditory acuity**

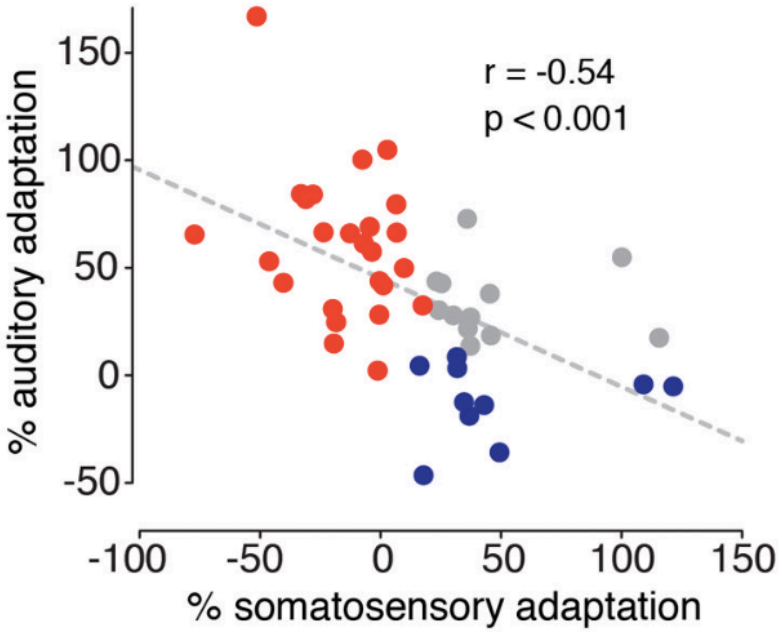


⇩ **auditory acuity**



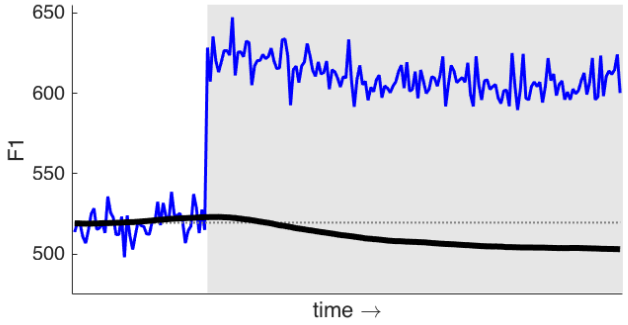
Some evidence for acuity-response relationship

Speakers' response to auditory perturbations is *negatively* correlated with their response to somatosensory perturbations



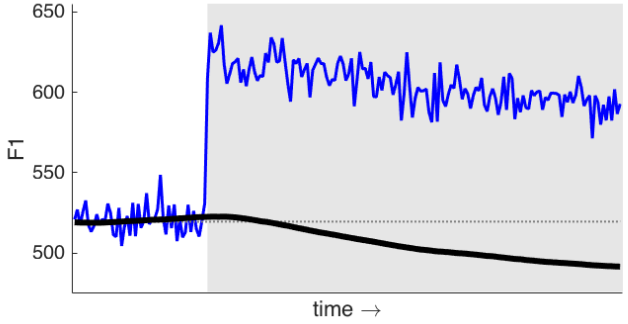
Lametti et al. 2012

Baseline response



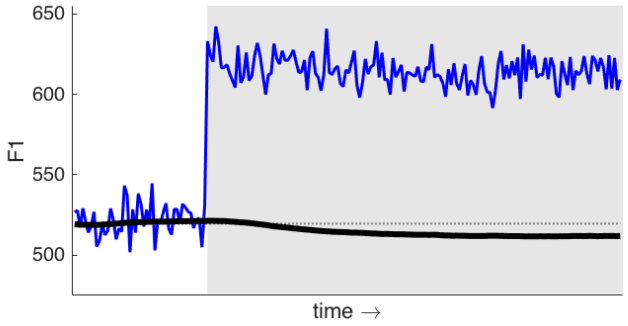
⇧ auditory acuity

⇩ somato-sensory acuity



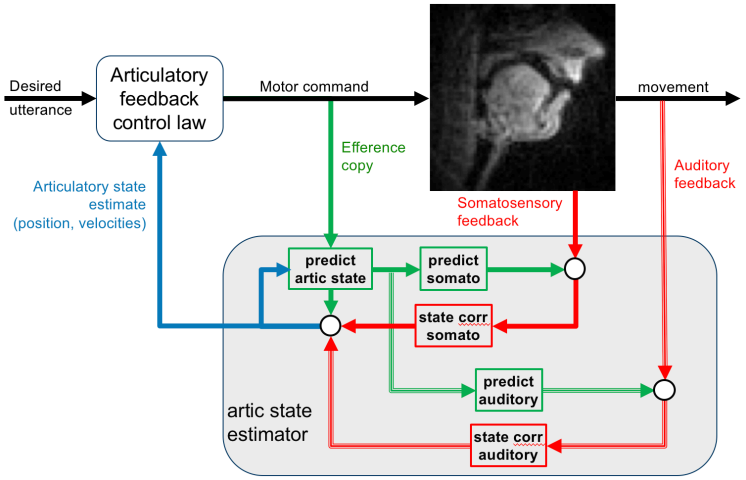
⇩ auditory acuity

⇧ somato-sensory acuity



FACTS model

- Is responsive to, but not reliant on, sensory feedback
- Produces stable speech in the presence of noise
- Reproduces full task-specific compensation for mechanical perturbations
- Reproduces partial compensation for auditory perturbations
- Models trade-off between auditory and somatosensory perturbation responses



What's next?

- Model neural system
- How is the prediction process learned and updated?
- Is multisensory feedback combined to estimate a single state or are auditory and somatosensory signals treated separately?

Computational implementation