– The Shape of Locomotion –

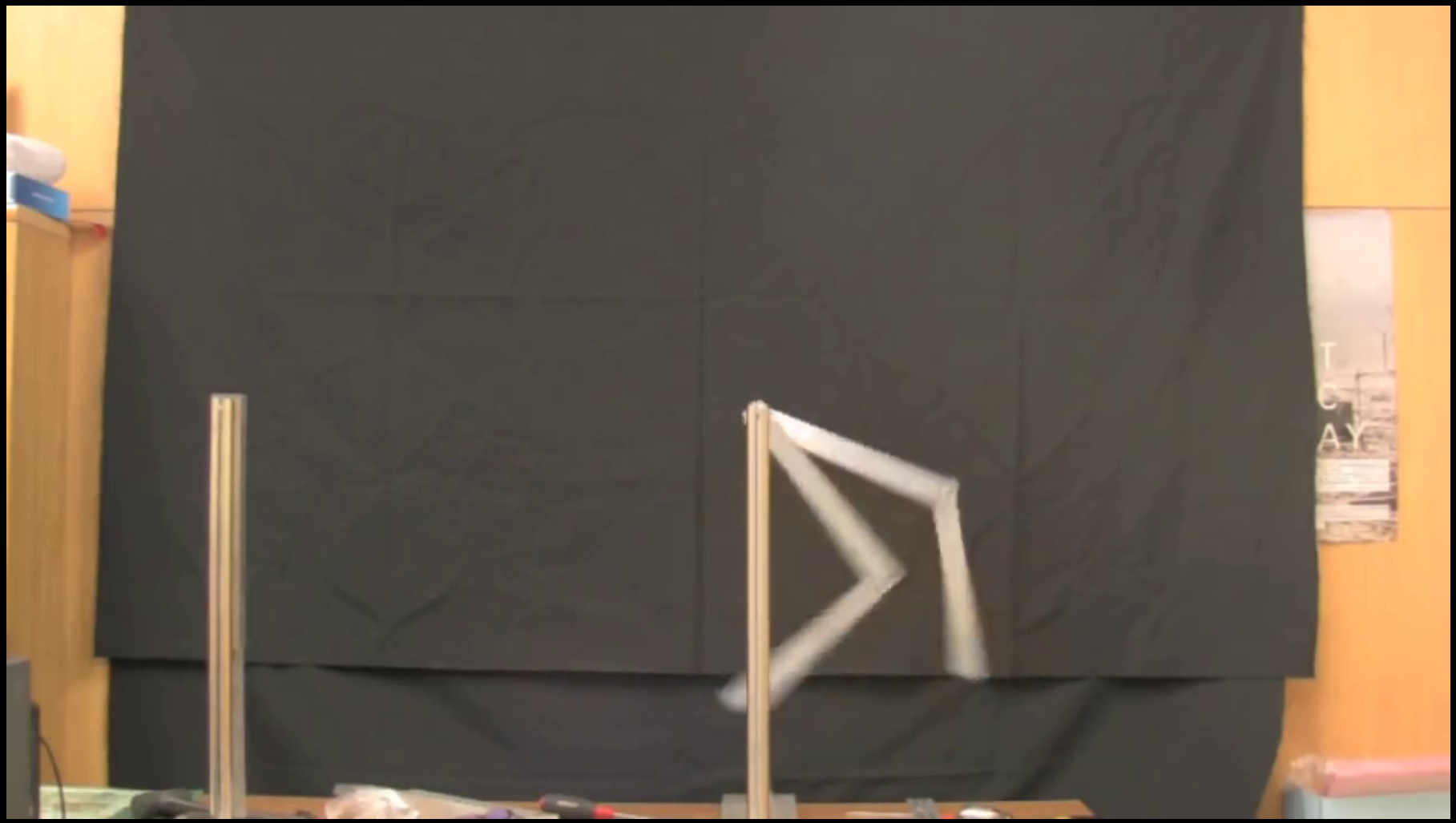
A Method for Large Scale Analyses of Intra-Limb Coordination

Falk Mielke*, Chris Van Ginneken, Peter Aerts

Functional Morphology, Universiteit Antwerpen

DZG Meeting, Jena
September 9^{th}, 2019

Chaos

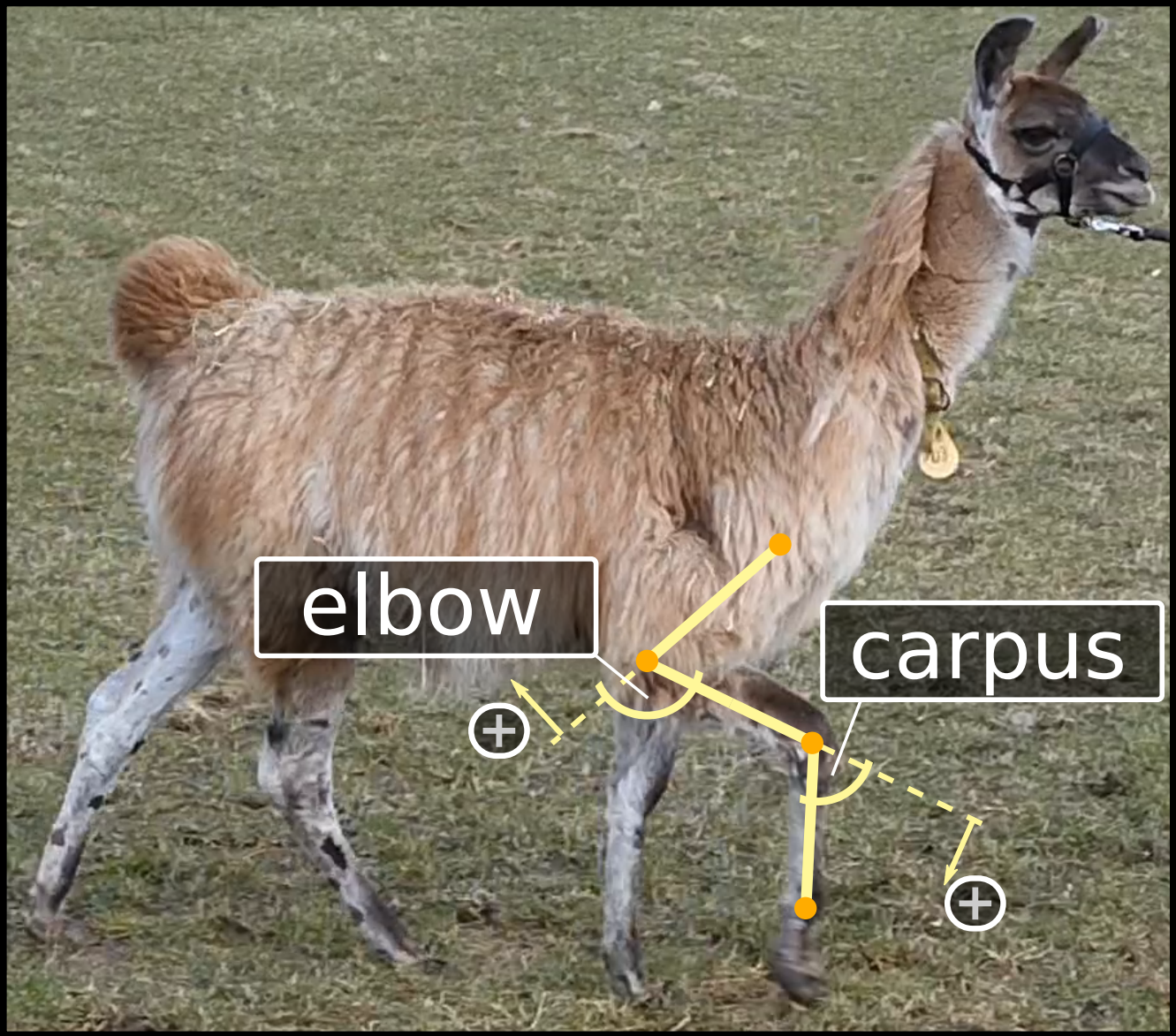


Shunichi Yamamoto, youtube N6cwXkHxLsU (Dec 2, 2011)
"High Performance Coupled Double Pendulum", played backwards

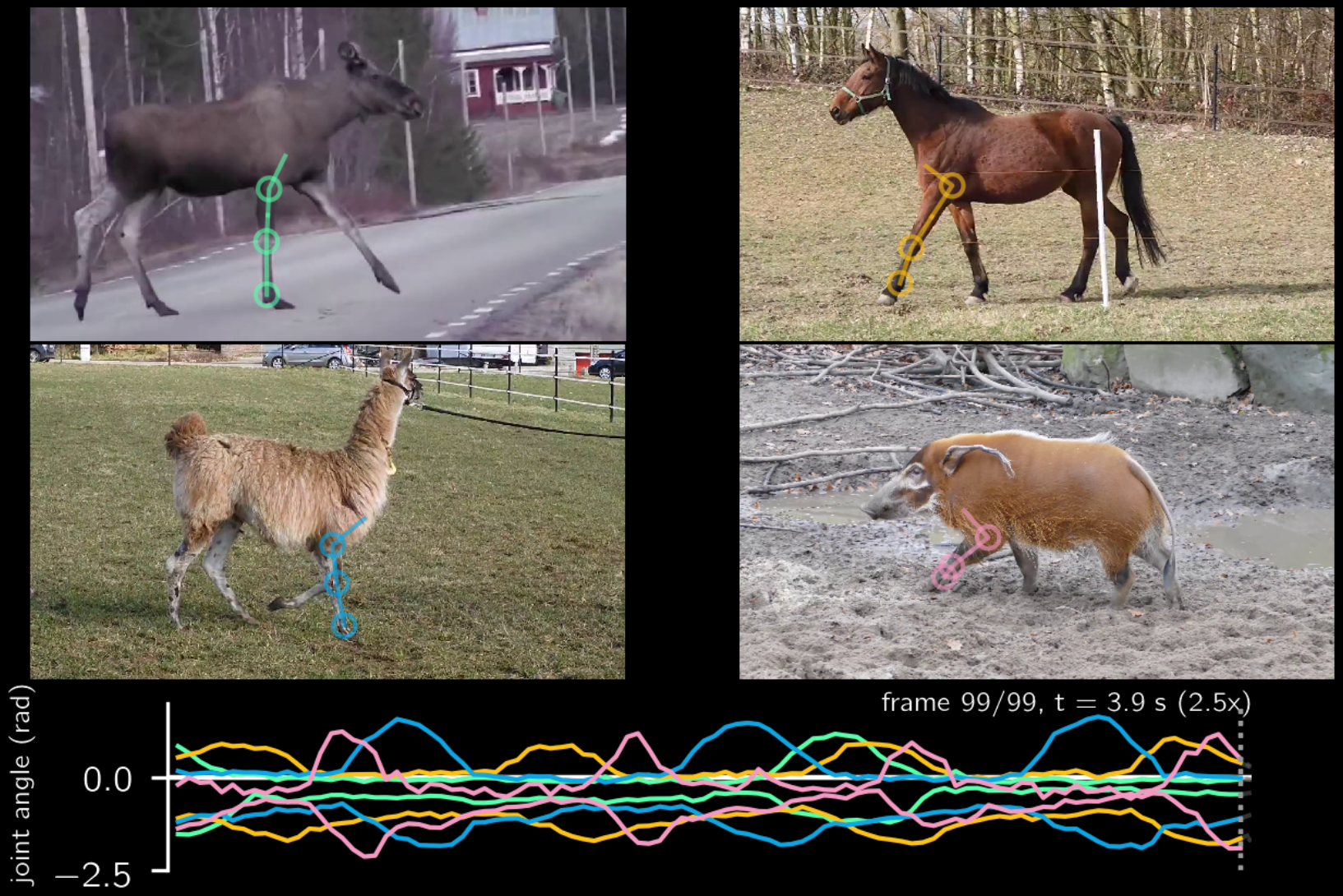
Control and Coordination

red river hog by *oschu1000*, youtube Z97wAh3IXWc (Dec 8, 2017)
moose by *ullabri*, youtube GEZ3Ton9w6A (Apr 27, 2011)

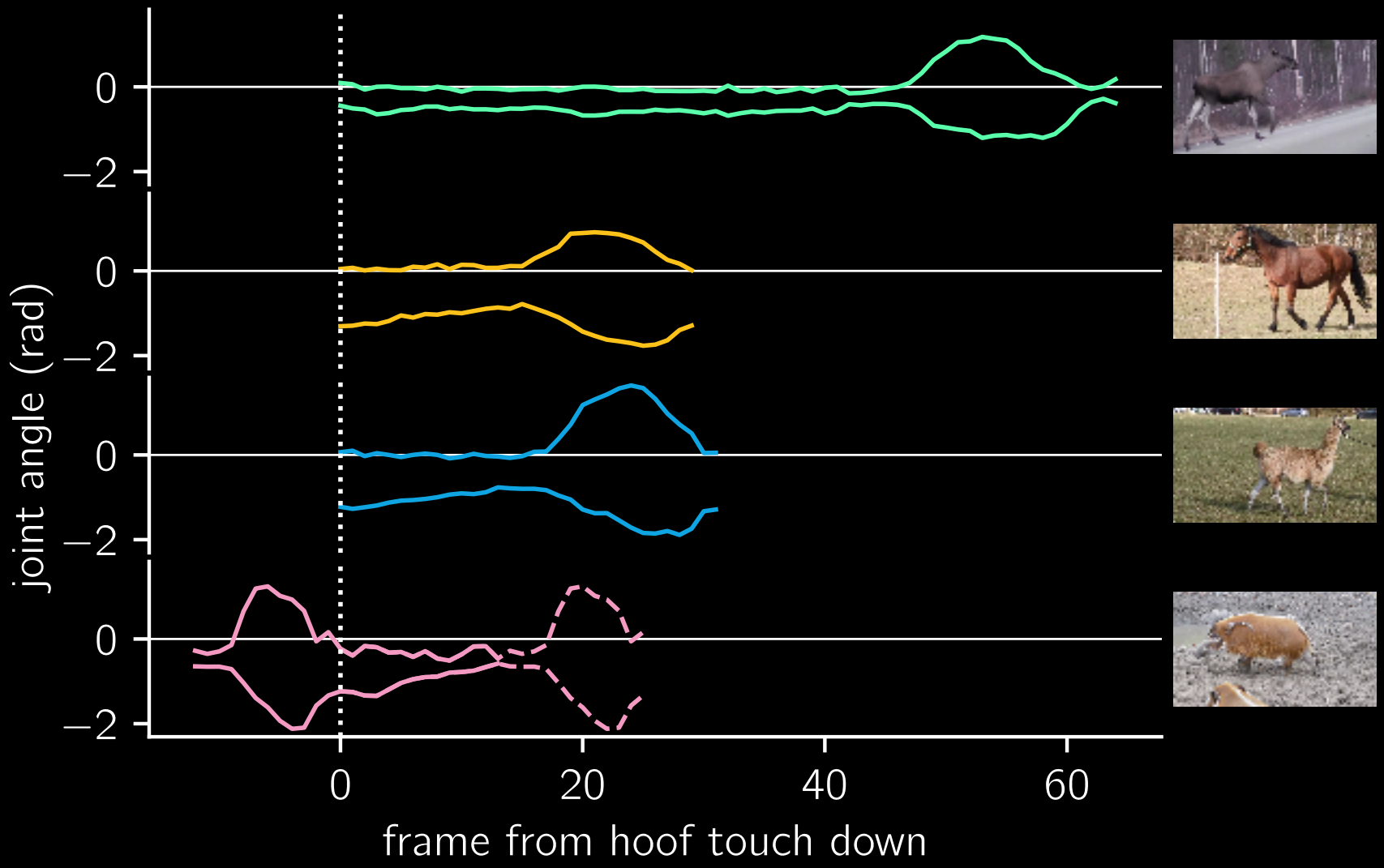
Joint Angles



Digitization



Conventional Alignment



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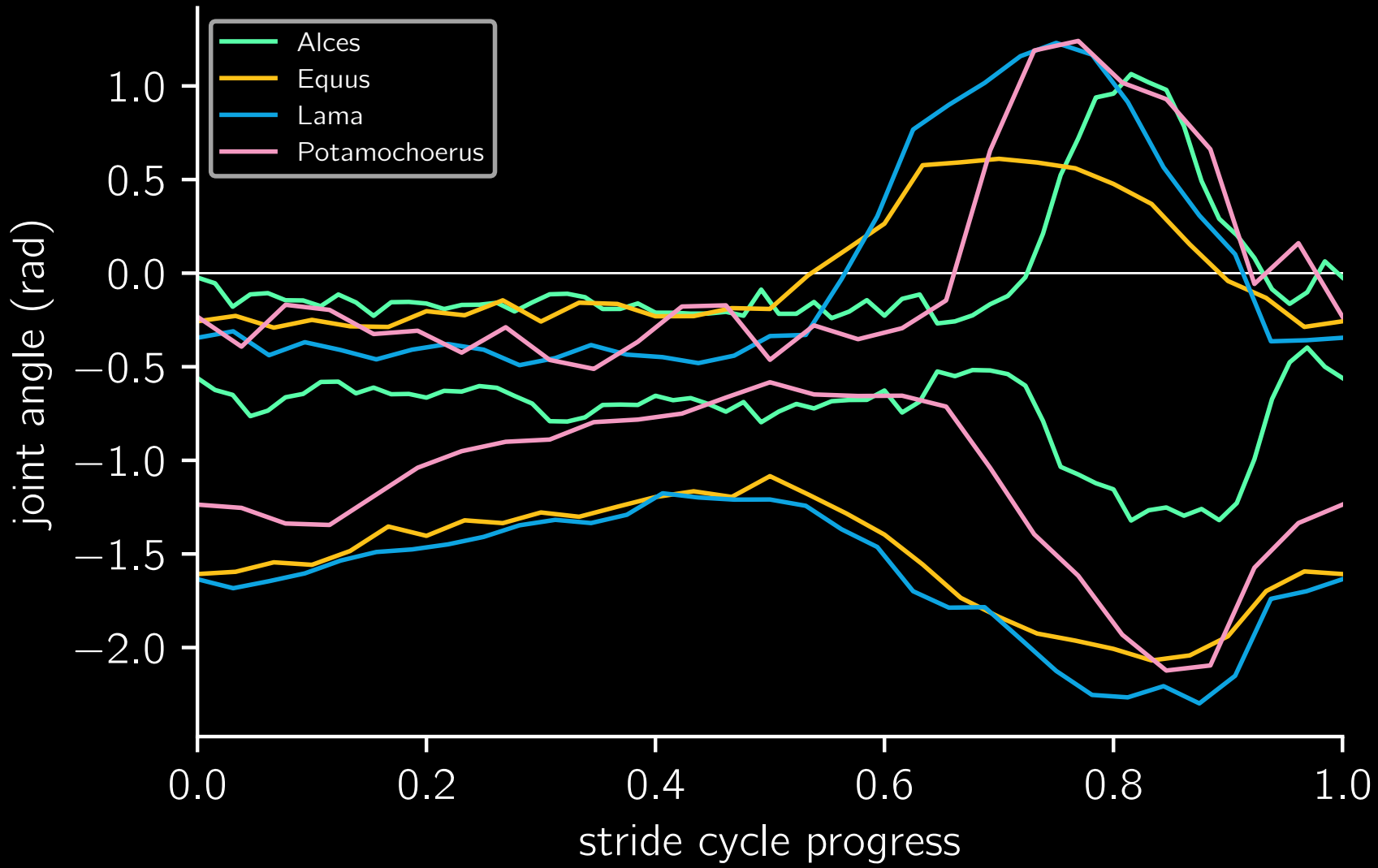
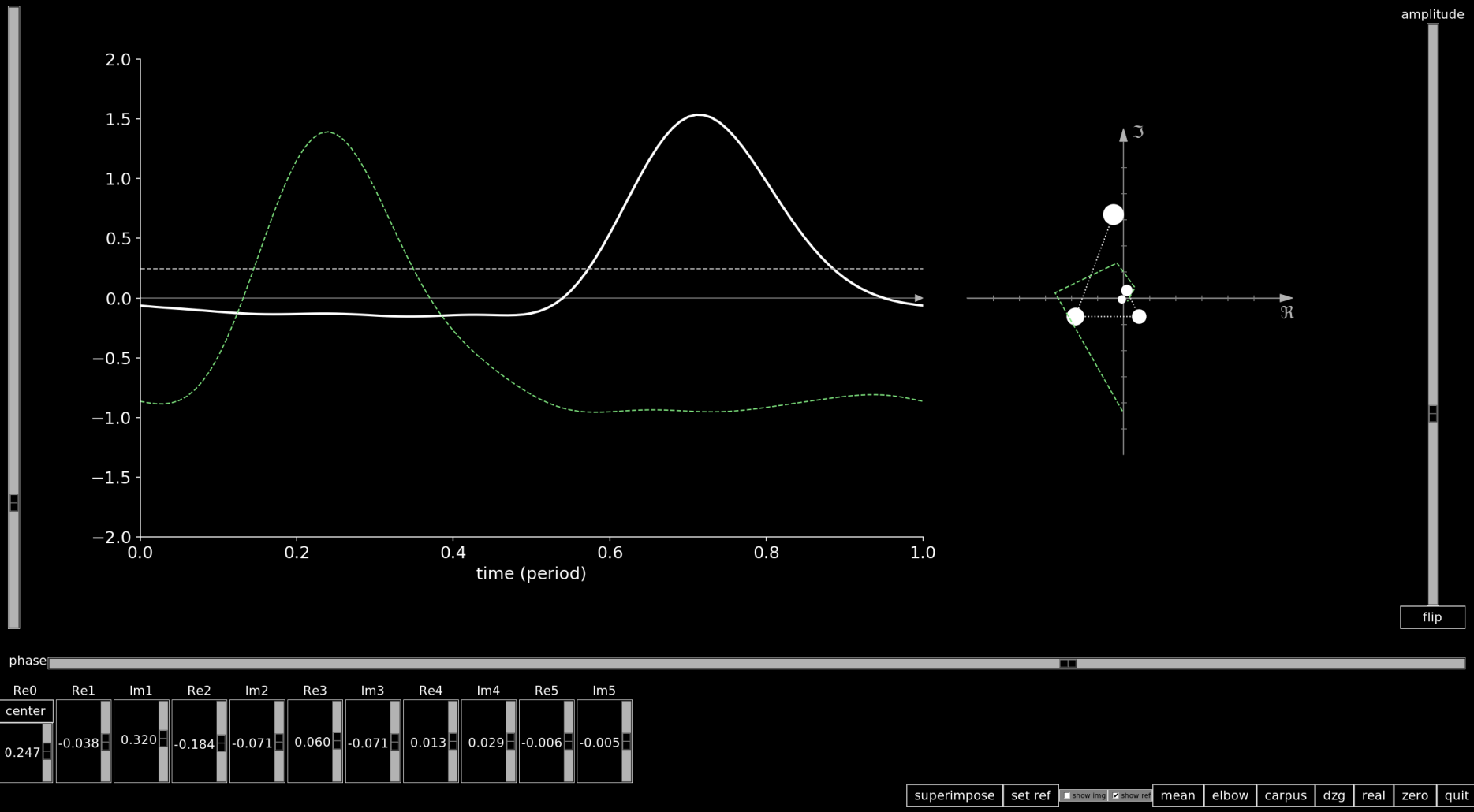
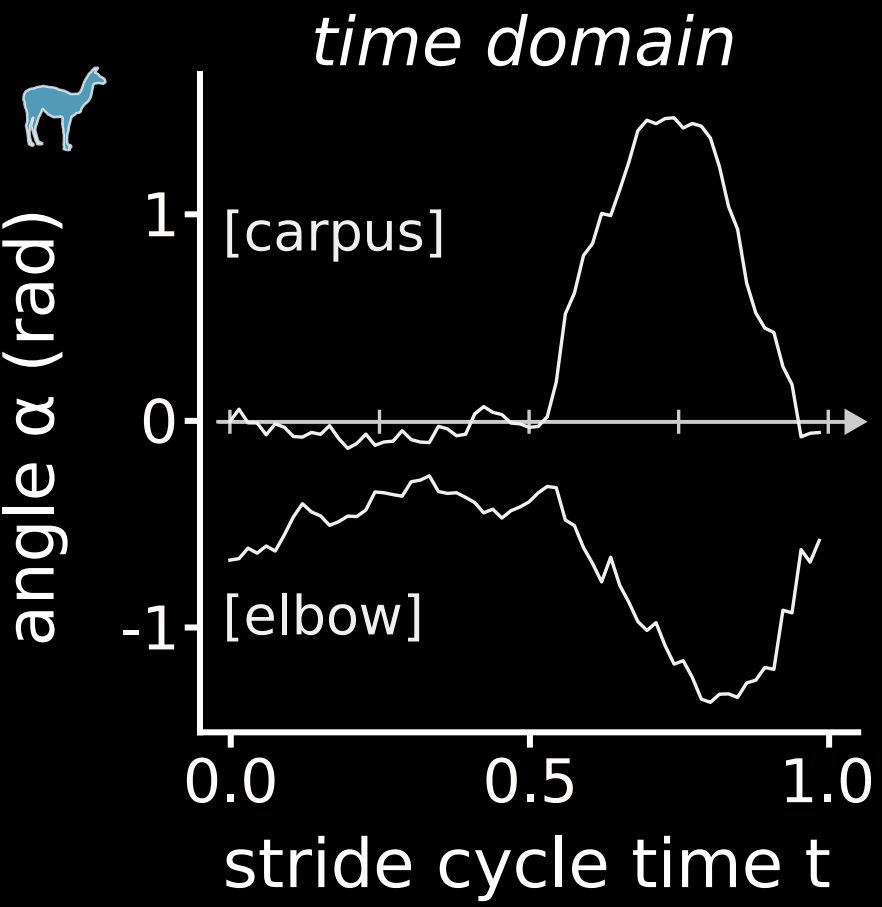


Fourier Series



Fourier Series Decomposition



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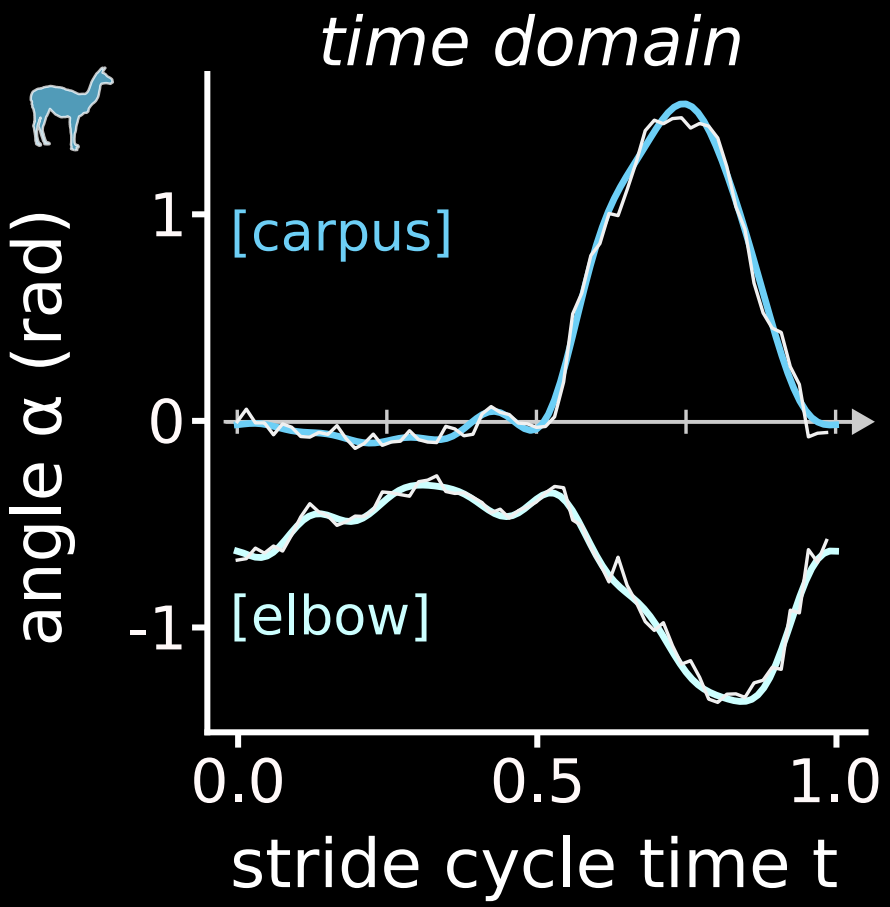

FSD:

$$f(t) = \sum_{n=0}^{N} (2 \cdot c_n) \cdot e^{2\pi i n \frac{t}{T}}$$

$$c_n = \frac{1}{T} \sum_{t=0}^{T} e^{-2\pi i n \frac{t}{T}} \cdot f(t) \quad \forall n > 0$$

$$c_0 = \frac{1}{T} \sum_{t=0}^{T} e^{0} f(t) = \langle f(t) \rangle$$

(Osgood, 2007)

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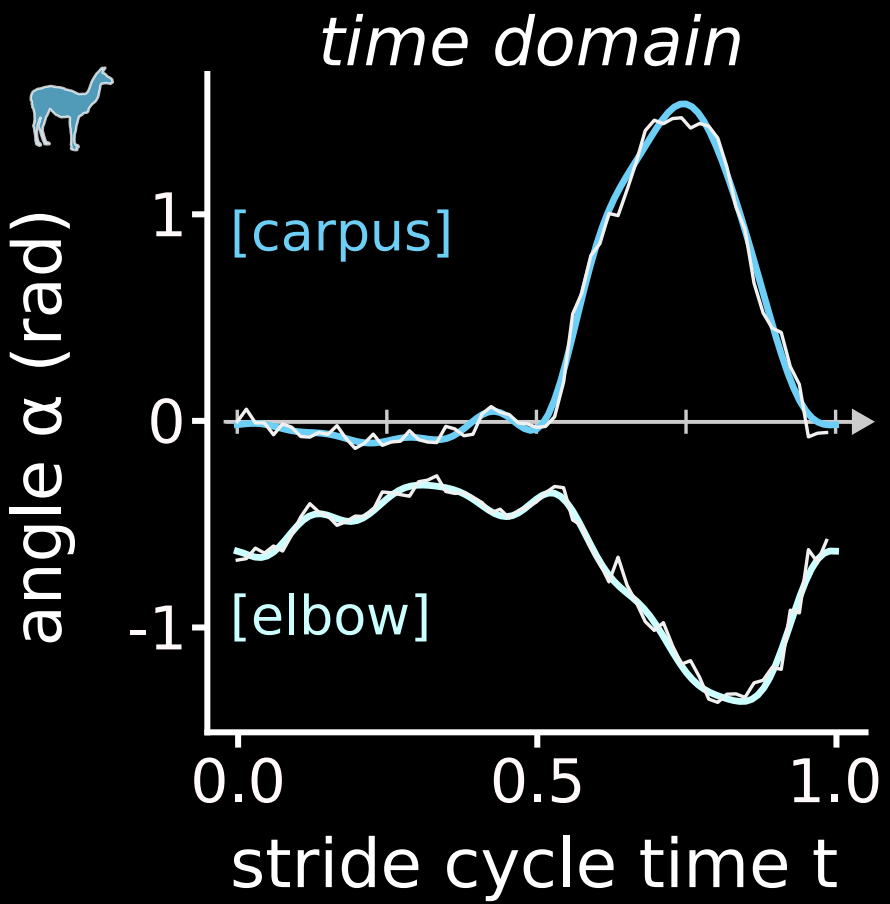

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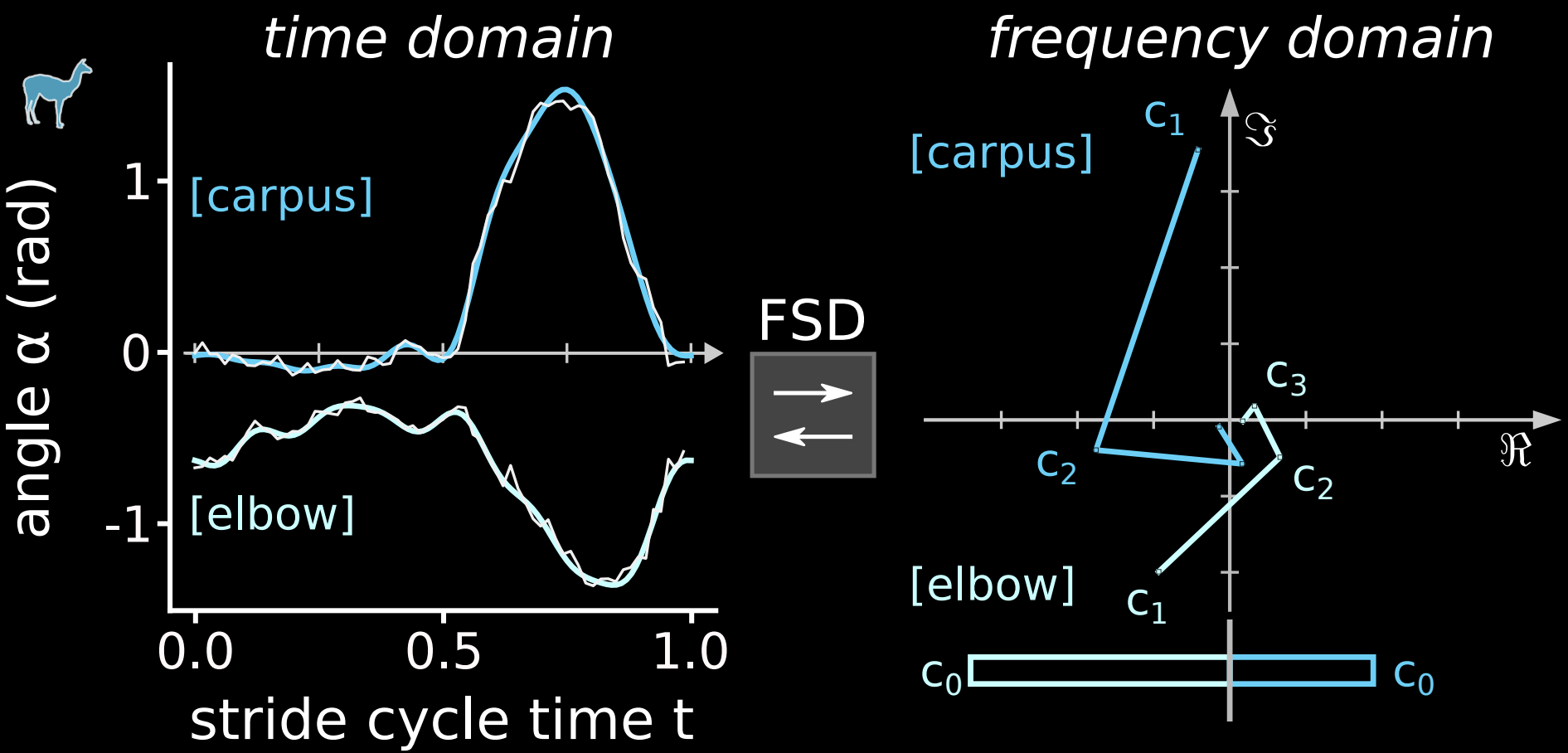

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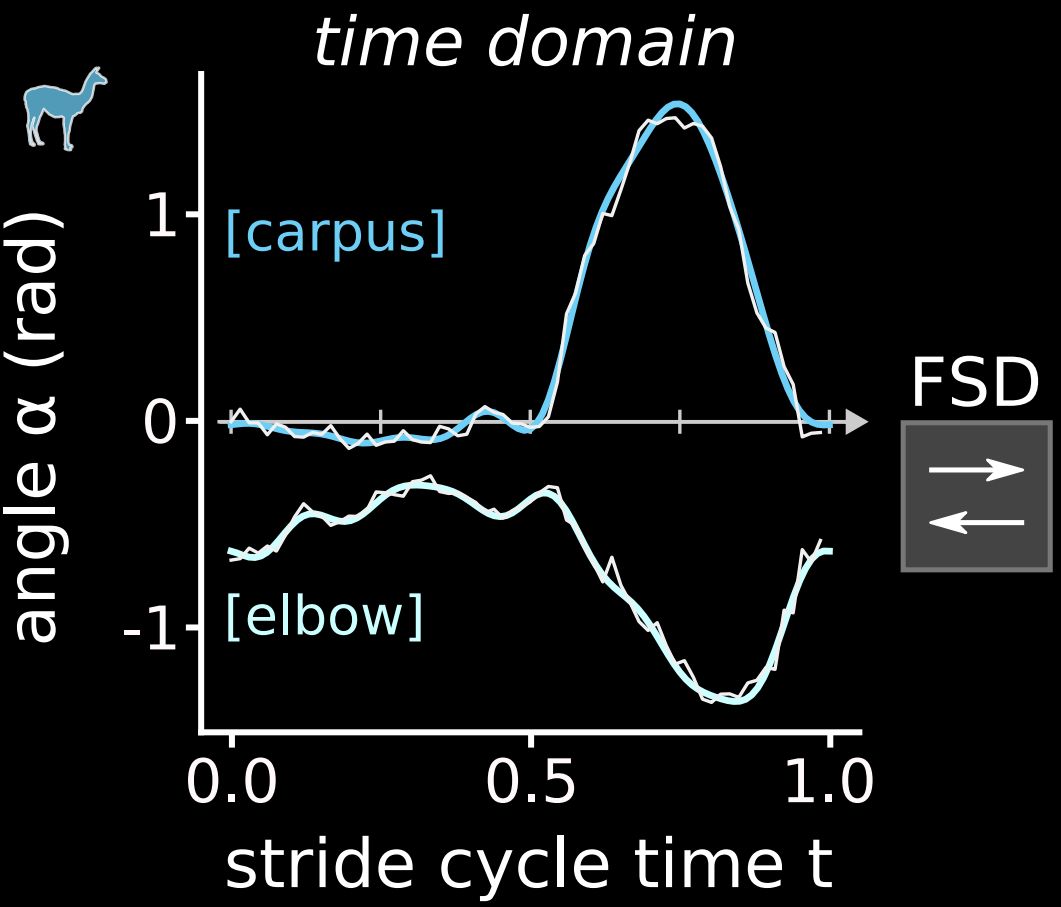

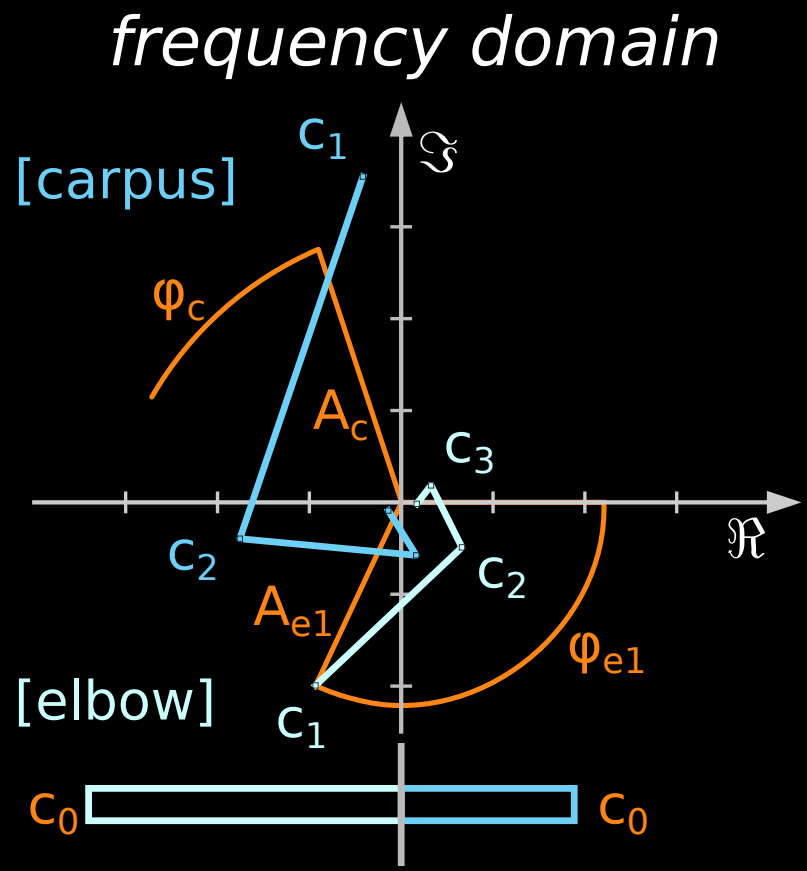

Superimposition

requires to calculate signal parameters (c_0, A, ϕ) from coefficients.

$$\text{mean} \qquad c_0 = \langle f(t) \rangle$$

$$\text{amplitude} \qquad A = \sum_{n=1}^{N} \sqrt{\Re(c_n)^2 + \Im(c_n)^2} = \sum_{i=1}^{N} |A_i|$$

$$\text{phase} \qquad \phi_n = \frac{1}{2\pi} \cdot arctan2\left(-\Im(c_n), \Re(c_n)\right)$$

$$\Phi = \frac{\sum_{n>0}^{N} (\phi_n - \phi_{n-1}) \cdot \frac{A_n}{n}}{\sum_{n>0} \frac{A_n}{n}}$$

affine components

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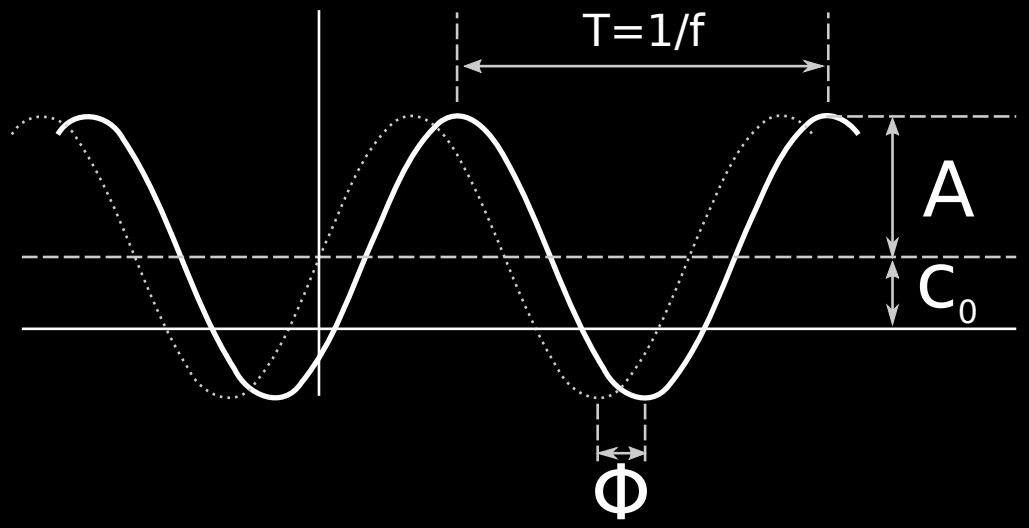
amplitude

phase



affine components

https://www.mathsisfun.com/algebra/amplitude-period-frequency-phase-shift.html

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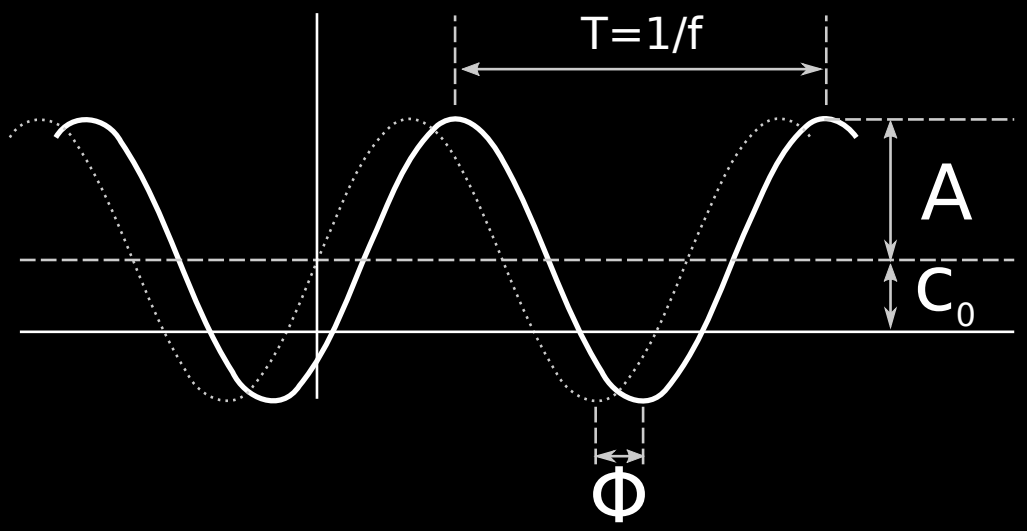

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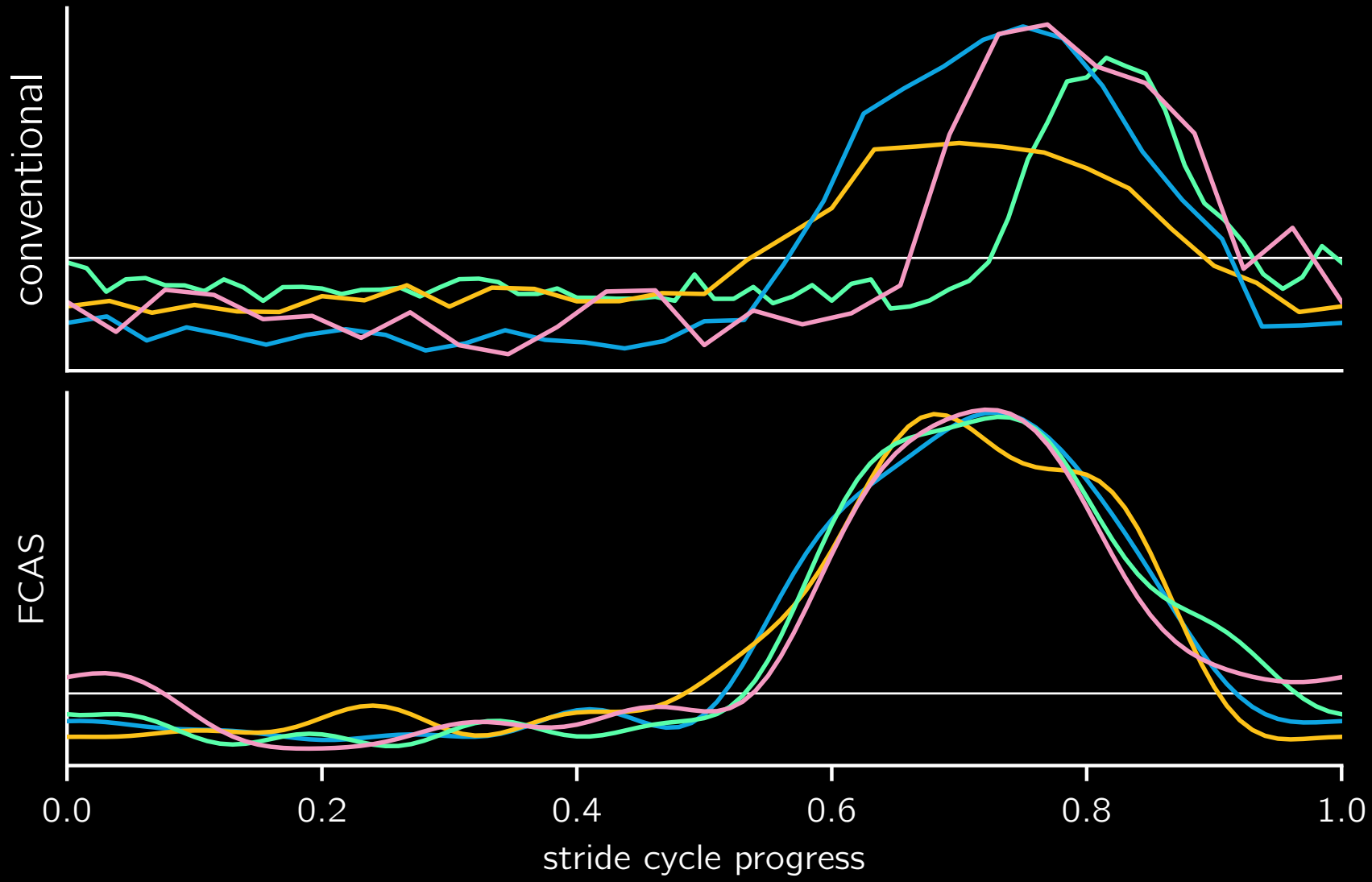
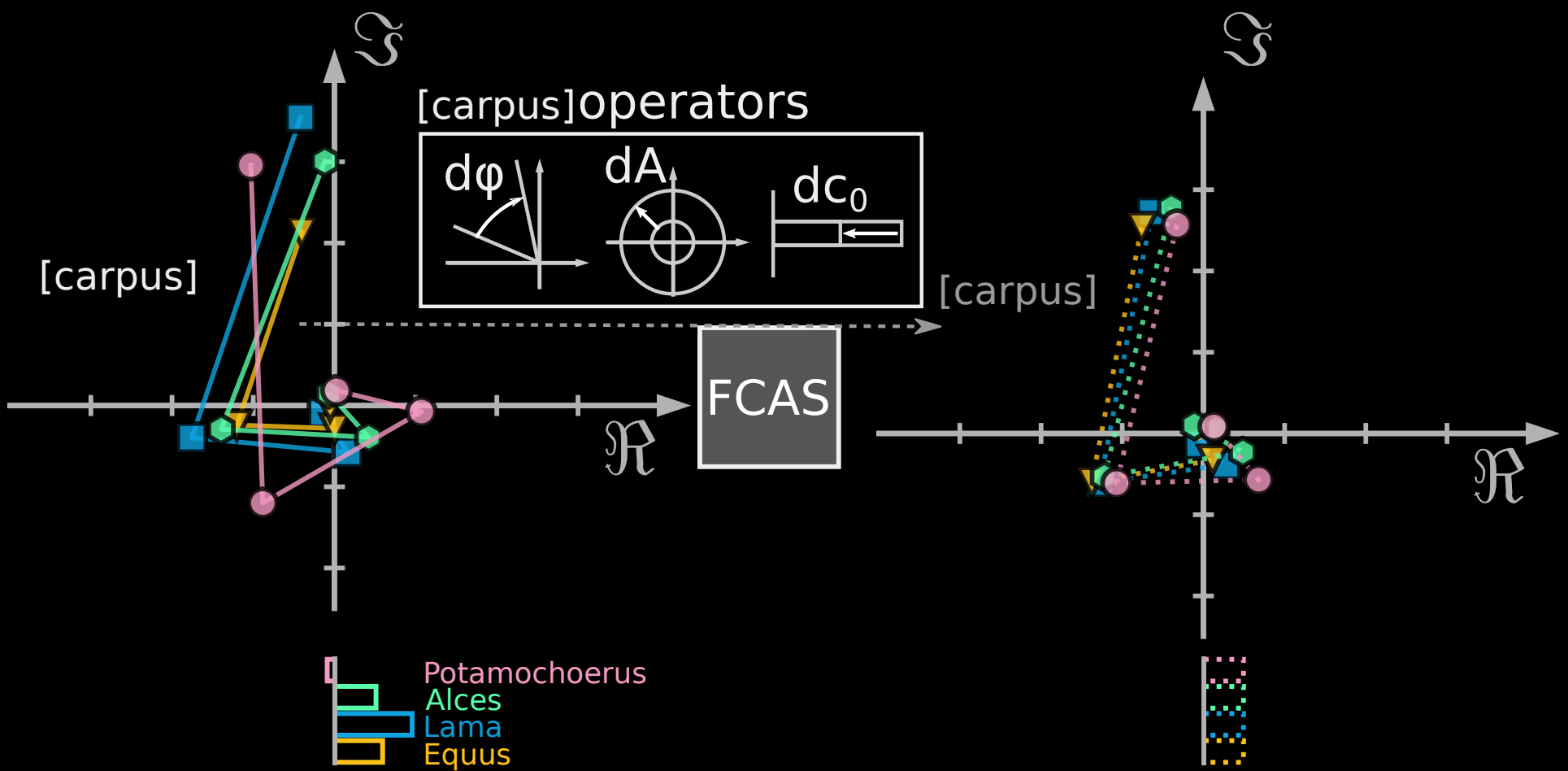
Fourier Coefficient Affine Superimposition



Transfer of Operators



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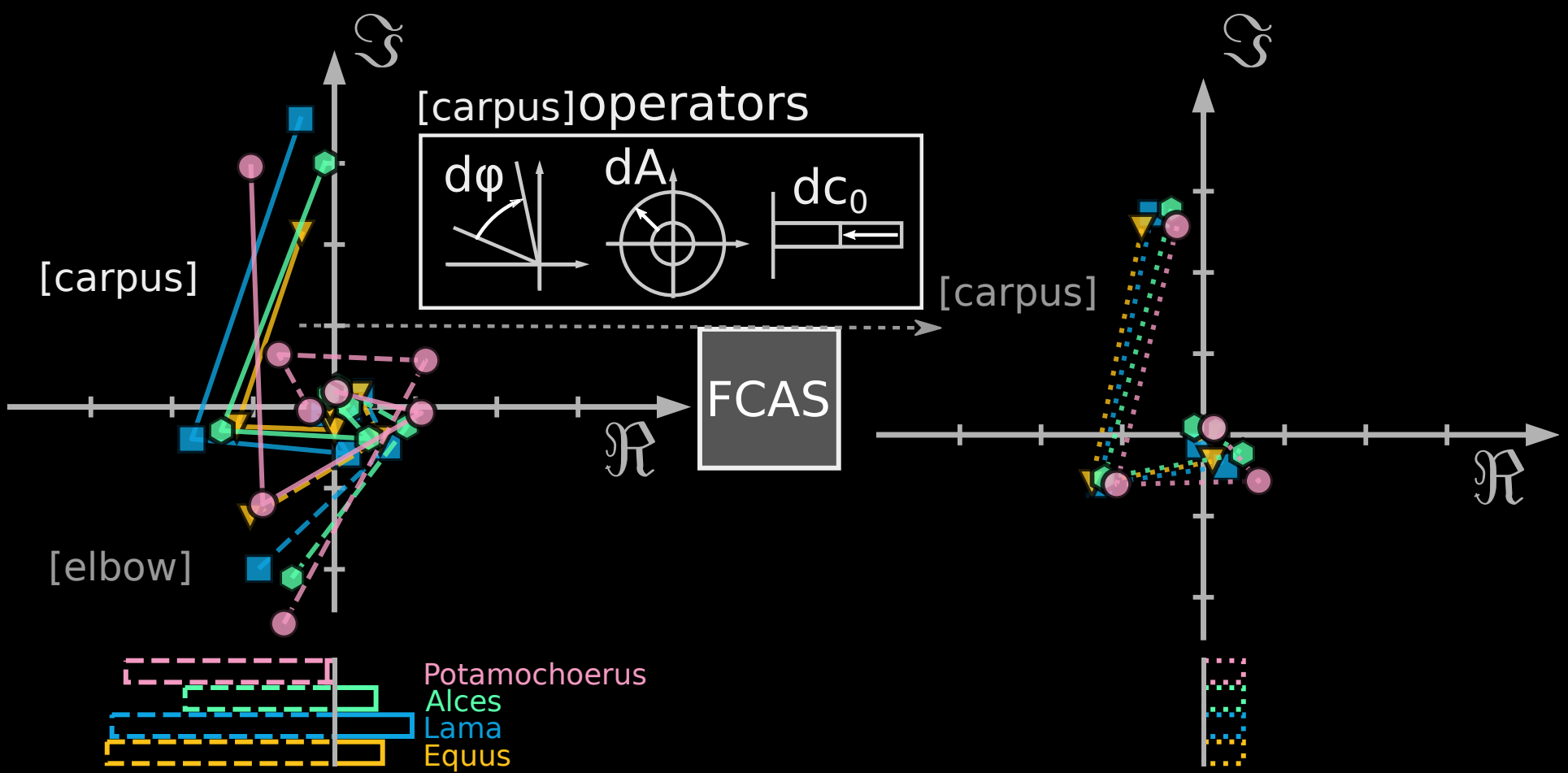

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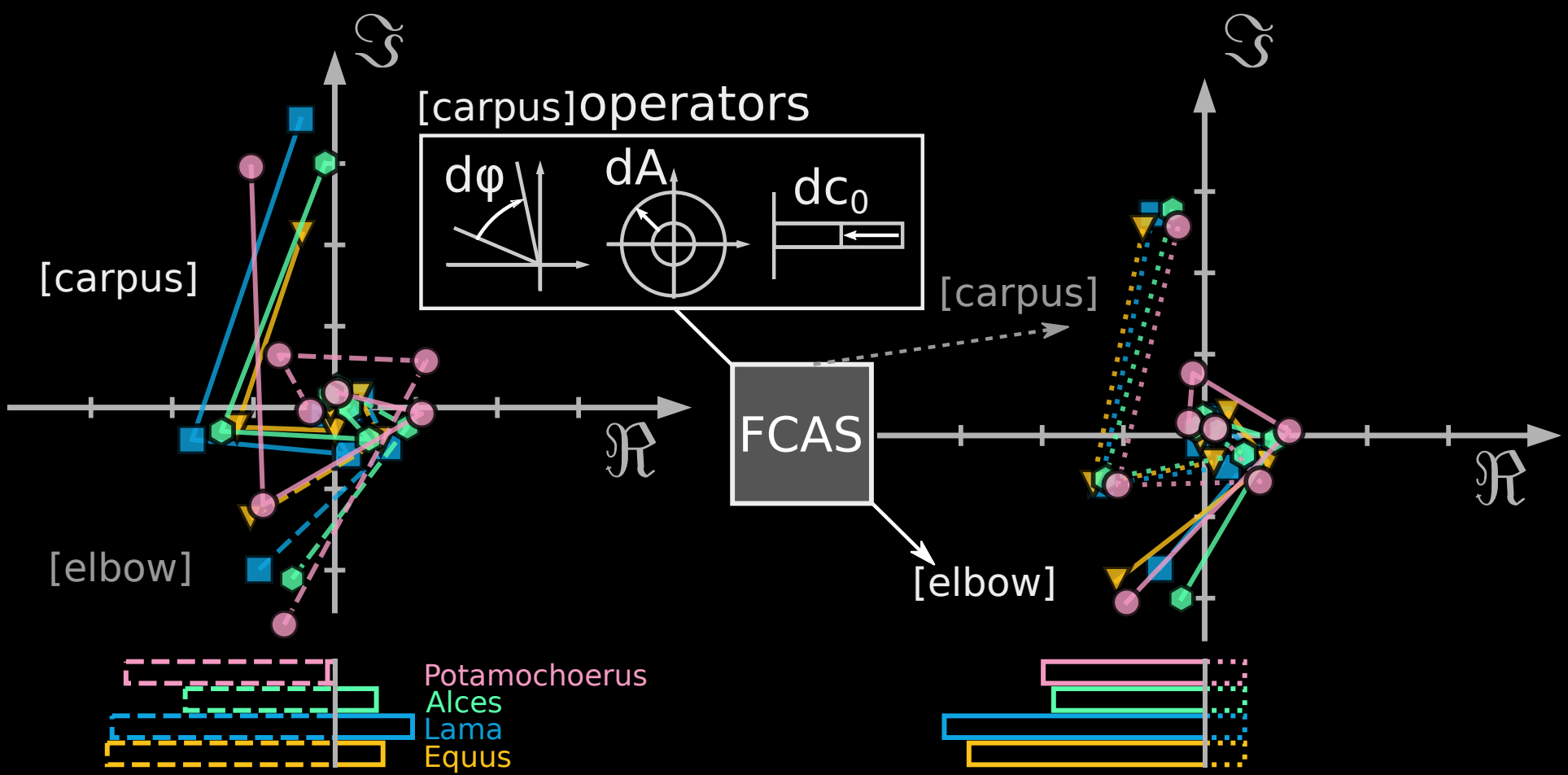

Relative Joint Profiles

- shape of elbow profiles
- relative timing
- relative amplitude
- optionally centered (posture)

dynamic similarity *Inter-Joint Coordination*

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The Shape of Locomotion

GM: geometric morphometrics
FCAS: Fourier Coefficient Affine Superimposition

Procedure:

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①	acquire data	ct/surface scan	videography
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③	alignment	Procrustes	FCAS
④	multivariate analysis	flexible	

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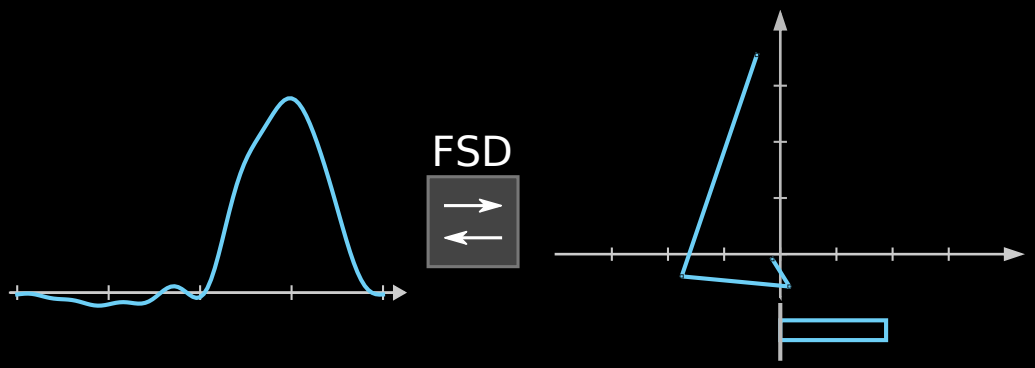
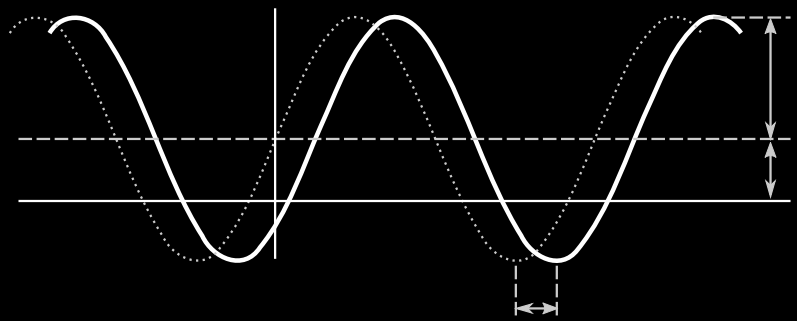
Summary

- Fourier Series
- affine components
- relative joint profiles
- geometric intuition





References

- Mielke, F., Van Ginneken, C., and Aerts, P. (2019). Quantifying intralimb coordination of terrestrial ungulates with Fourier Coefficient Affine Superimposition. *Zoological Journal of the Linnean Society. Under Revision.*

Osgood, B. (2007). The Fourier Transform and its Applications. *Stanford Engineering, course EE261.*

 @UAFunMorph

 mielke-bio.info/falk/dzg

Thank you!