Divergence of Movement (or rather; stability)

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And of course Deepak, for organizing, and inviting me.

My goals for today

- Explain how I think about (gait) stability
- To show you how Local divergence exponents (maximum Lyapunov exponent) is calculated (including nitty gritty details!)
- Explain why I think is a good tool to quantify gait stability

I will not talk (too much about)

- Mathematical origins of Lyapunov exponent (be happy to tell you later, over drinks)
- It’s use in Chaos, dynamical systems (see above)
- ‘Shuffling’ procedures.

The reason I don’t talk about these things is because I feel they;

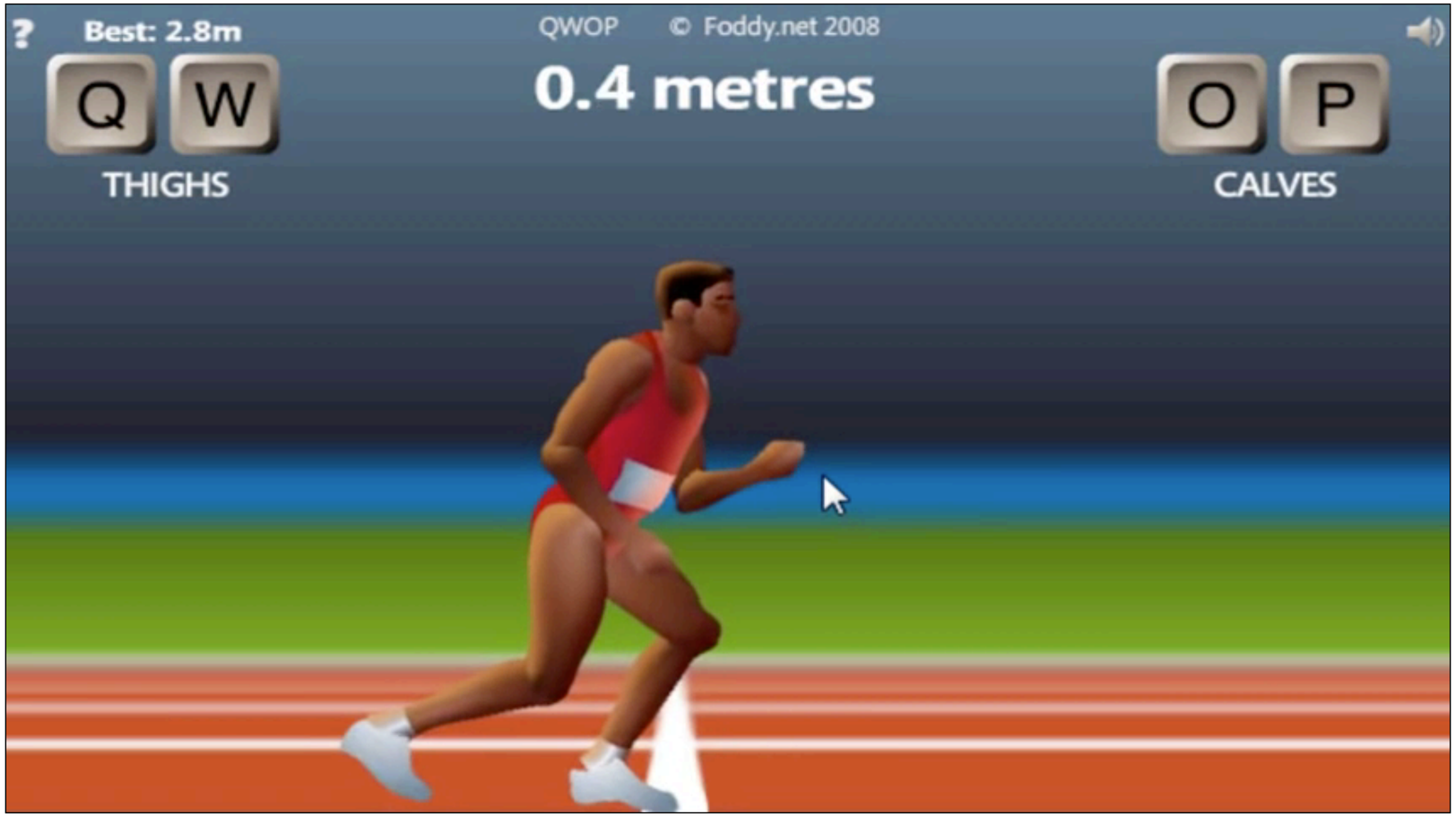
- Do not help you to understand how we currently use it
- Would take time away from actually understanding what it is you calculate

If you’re very interested in these things, and want to know more, I’m happy to chat during the hands on sessions.

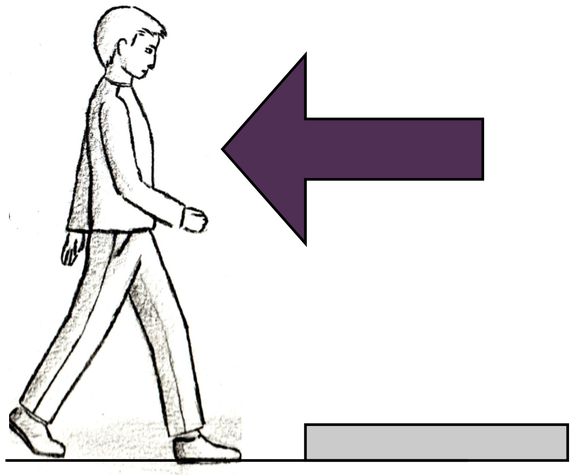
During workshop you will:

- Calculate local divergence exponents yourself
- Look at the effect of parameter choices (embedding, delay), and see that (in the end) they don’t matter (that much)

1. How do I think of gait stability?



3 aspects of gait stability



Steady state gait stability

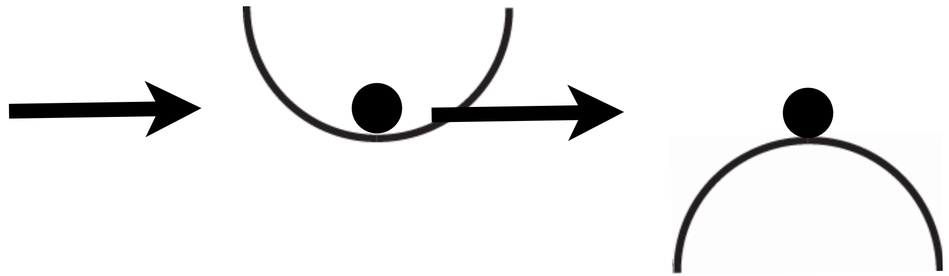
Reactive gait stability

Proactive gait stability

Bruijn et al., 2013 J R Soc Interface

2. How to calculate local divergence exponents?

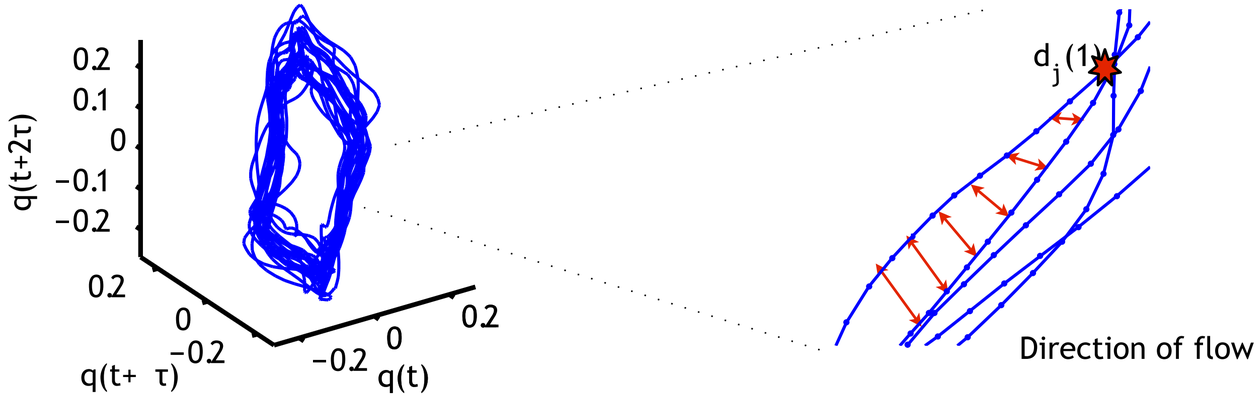
Which one is (more) stable?



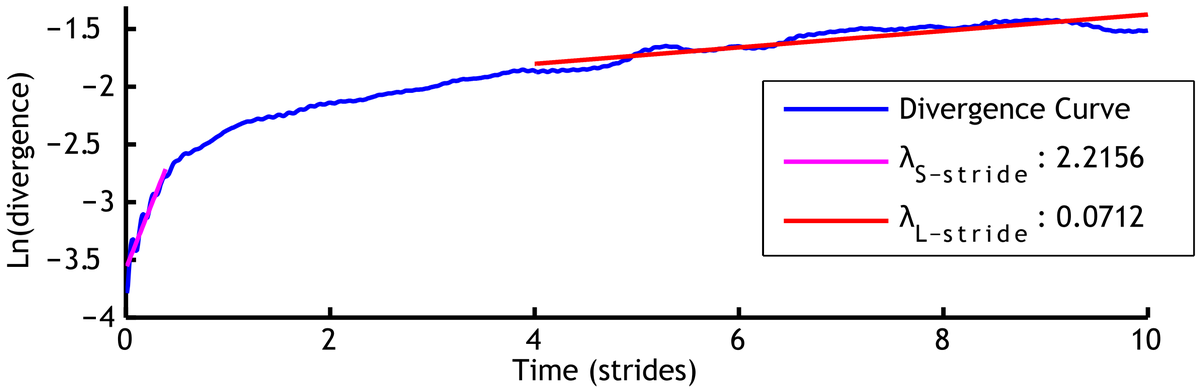
Local divergence exponents

- the small variations in gait can of course be regarded as small perturbations
- in which case it would be interesting to see what happens to these small perturbations over time
- this is exactly what local divergence exponents do

Local divergence exponents



Local divergence exponents



HEEEEEELP!

5 dimensional state space? Dimension? Delay? HELP ME OUT HERE!

Off to the blackboard, and to the code. This part will be quite interactive, so please, be interactive with me.

To conclude; state space

- Best not filter your data
- Multiple dimensions; otherwise, we cannot identify nearest neighbours accurately
    - amount of dimensions; depends on signal, better too high
    - delay; depends on signal. Ideally, such that it contains minimal information about original signal
- 3D or separate dimensions? Open discussion. Different dimensions yield different results, which suggests that they are not fully “coupled”

Van Schooten et al., 2013; Raffalt et al 2020

To conclude; state space

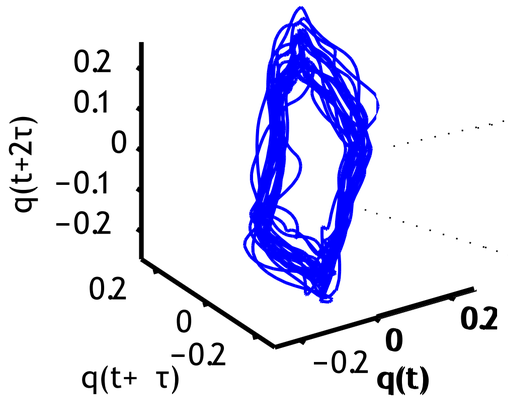
Table 2
Intra-class correlations (*ICC*) and smallest detectable differences (*SDD*) within sessions, where state space reconstruction is based on (1) mediolateral accelerations with dimensions determined by *GFNN* and time delay determined by I_{min}; (2) mediolateral accelerations with 7 dimensions and time delay determined by I_{min}; (3) mediolateral accelerations with 7 dimensions and a time delay of 6 samples, and (4) 3D accelerations, 9 dimensions and a time delay of 24 samples.

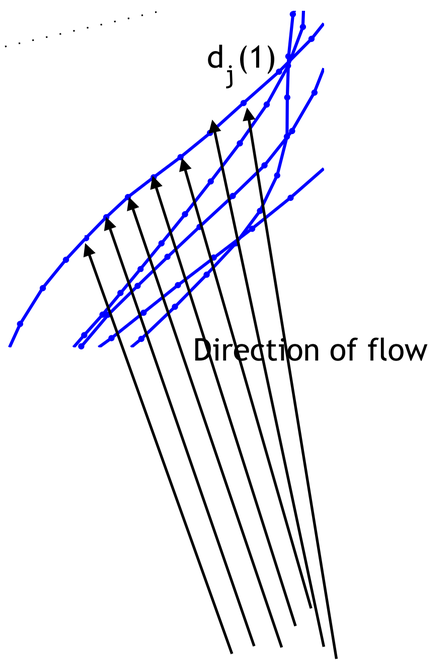
Method	Session 1 (trial 1 vs. 2)				Session 2 (trial 3 vs. 4)			
	ICC	*p*	*SDD*	$\frac{SDD}{\text{Mean } \lambda_s}$	*ICC*	*p*	*SDD*	$\frac{SDD}{\text{Mean } \lambda_s}$
1	0.79	<0.001	0.58	0.38	0.78	<0.001	0.48	0.31
2	0.81	<0.001	0.64	0.41	0.74	<0.001	0.50	0.33
3	0.92	<0.001	0.12	0.08	0.83	<0.001	0.15	0.11
4	0.80	<0.001	0.07	0.11	0.79	<0.001	0.09	0.13

Van Schooten et al., 2013

To conclude; local divergence exponent

- ‘Block’ half a period for finding nearest neighbours





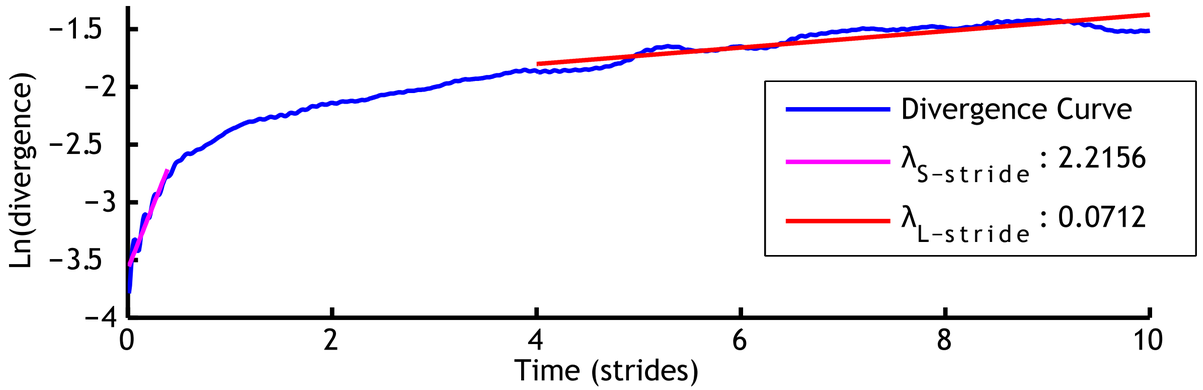
NOT valid nearest neighbours!

- Where to calculate slope? I suggest 0-0.5 stride
- Express slope as log(div)/stride (instead of /sec)

Van Schooten et al., 2013

To conclude: why not ‘maximum Lyapunov exponent’?

Because although the calculation is exactly the same, but, for a ‘true’ maximum Lyapunov exponent to be present, there needs to be a linear region in the plot. There clearly is not, so I (and many people with me) agree that local divergence exponent is a more correct term.



To conclude: I discussed only one algorithm

- There's also Wolf's algorithm
- Which has been suggested to work better for shorter data sets (see for discussion on time series length my keynote)
- But in my modelling (unpublished, see later) doesn't seem to work

Wolf 1985; Cignetti et al 2010

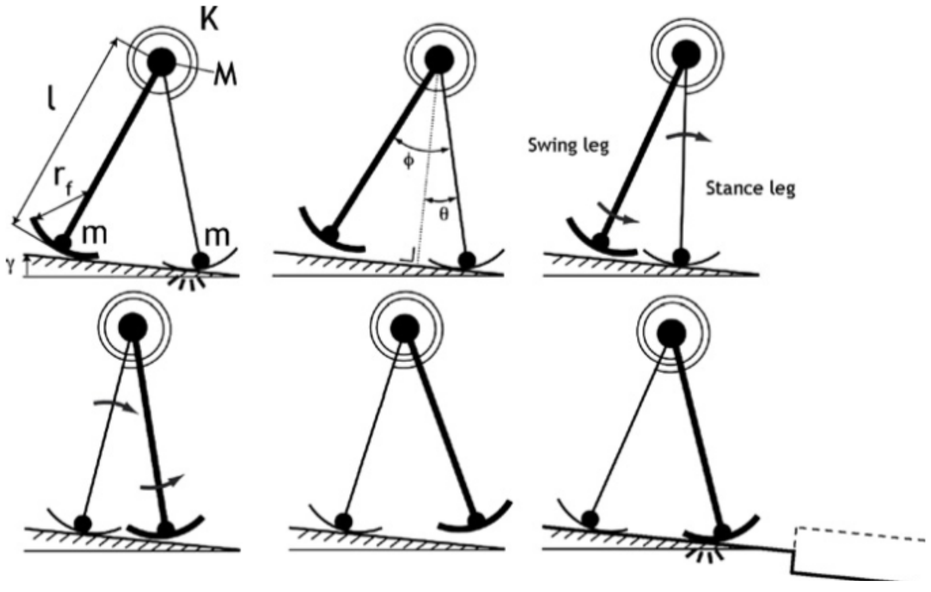
3. Why local divergence exponents?

- Theoretically sound (see previous slides)
- Simple models (to some extend)
- Experimental studies (largely)
- Larger cohort studies

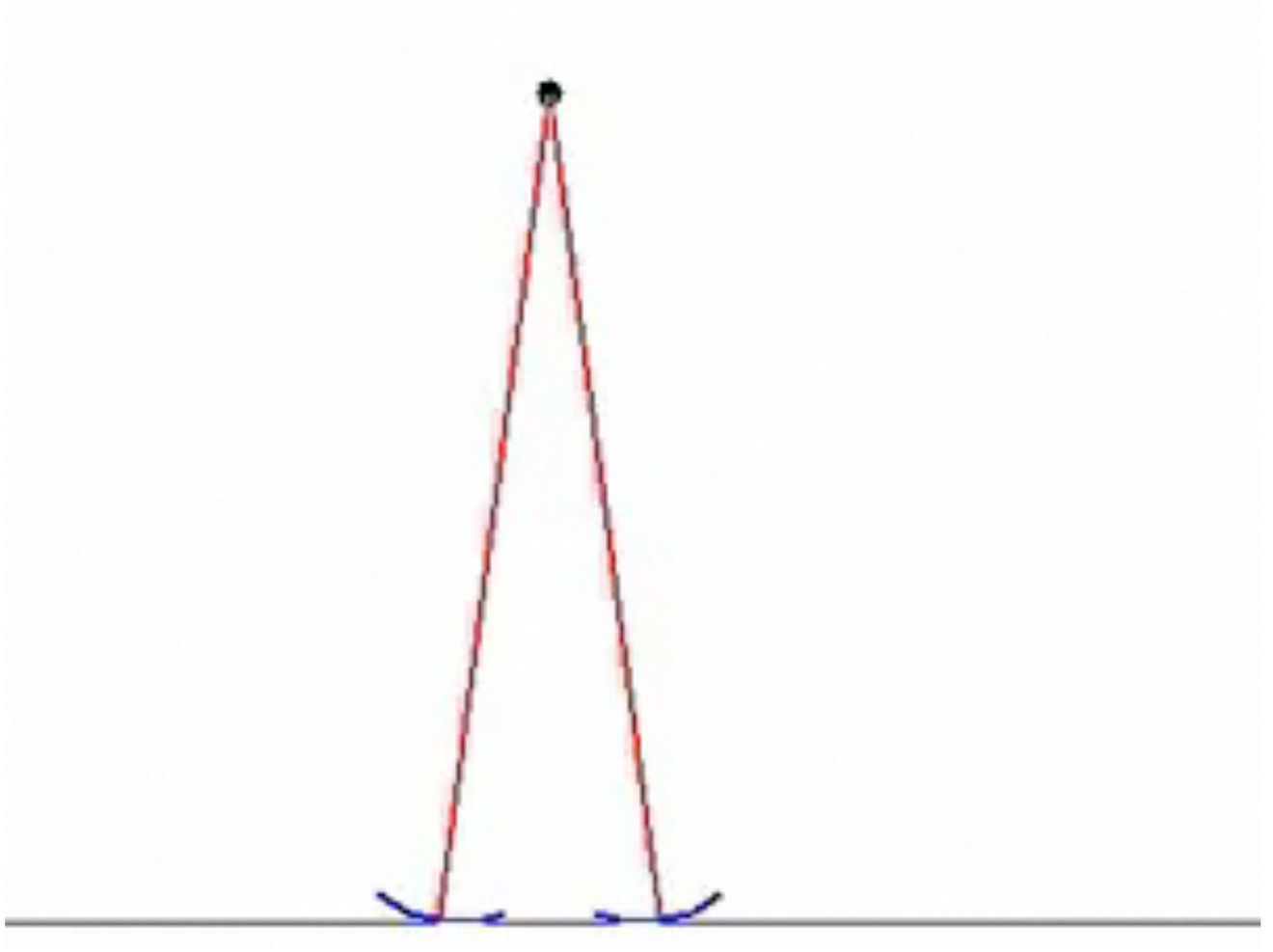
Bruijn et al. 2013

Simple models

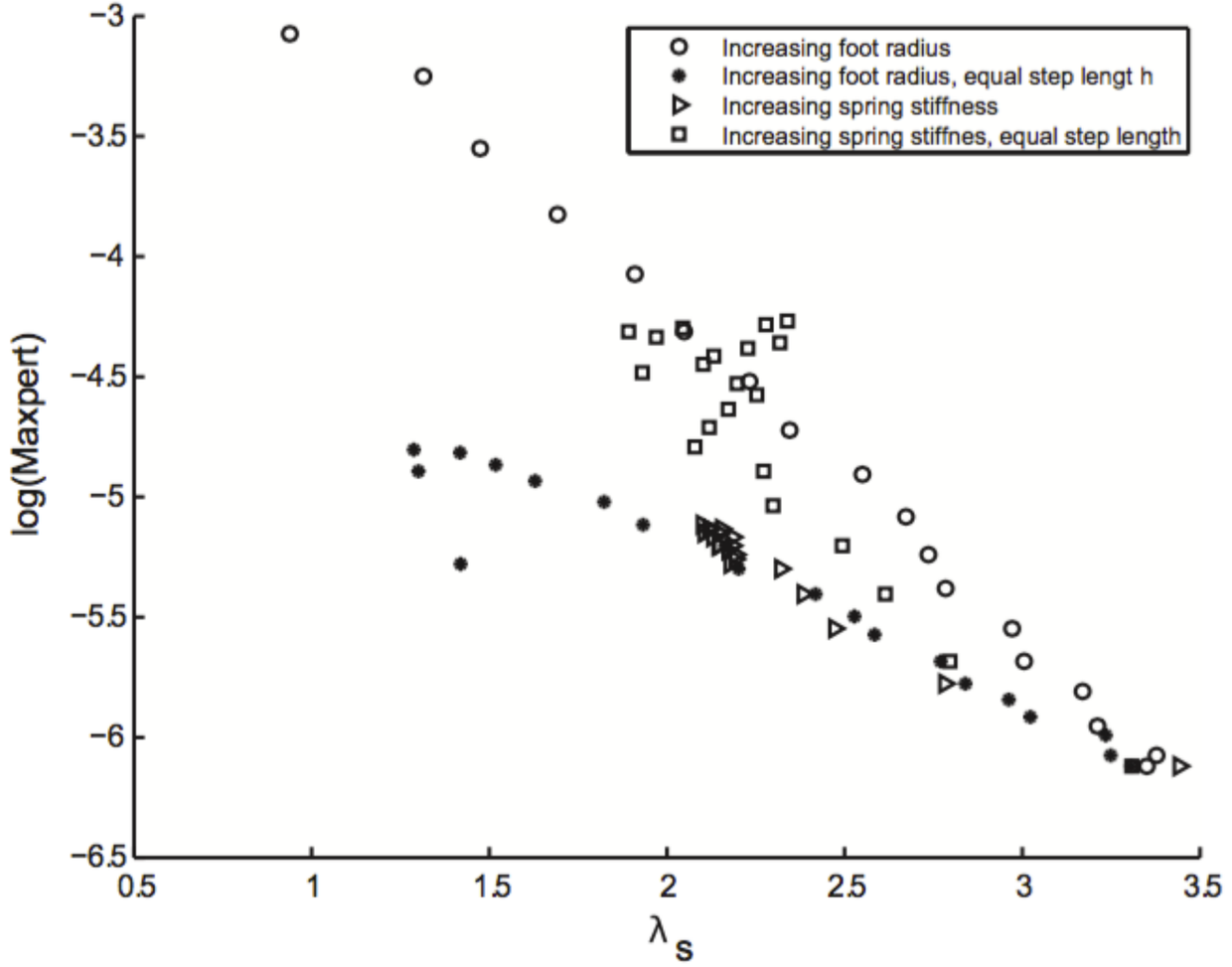
- test model stability (what step down does it fall?)
- generate time series
- calculate stability metric
- vary parameter
- repeat



Bruijn et al 2012

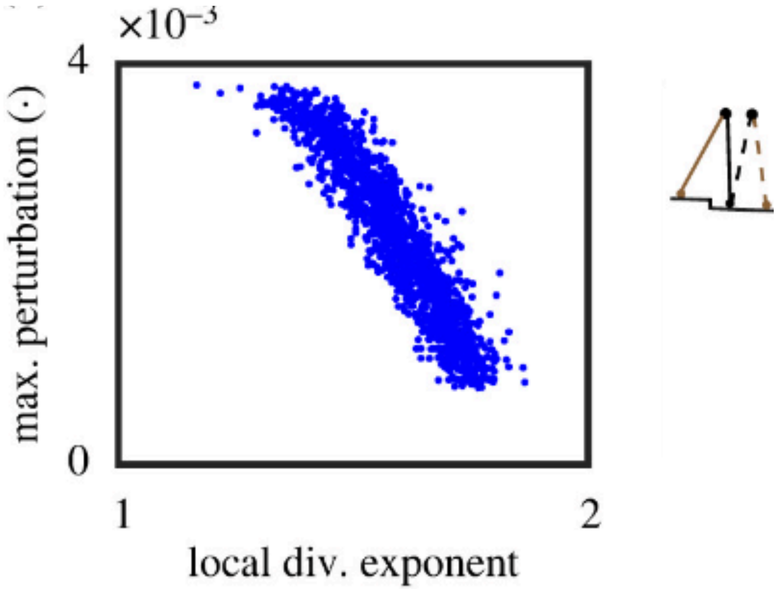


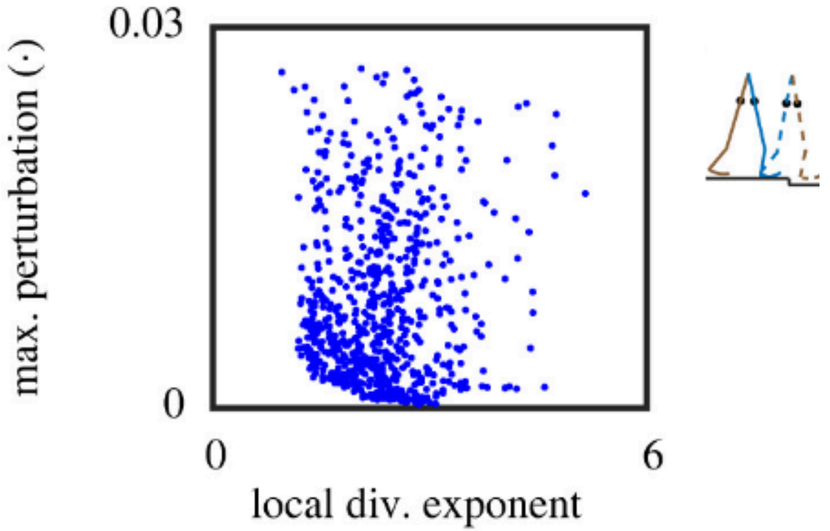
Results model

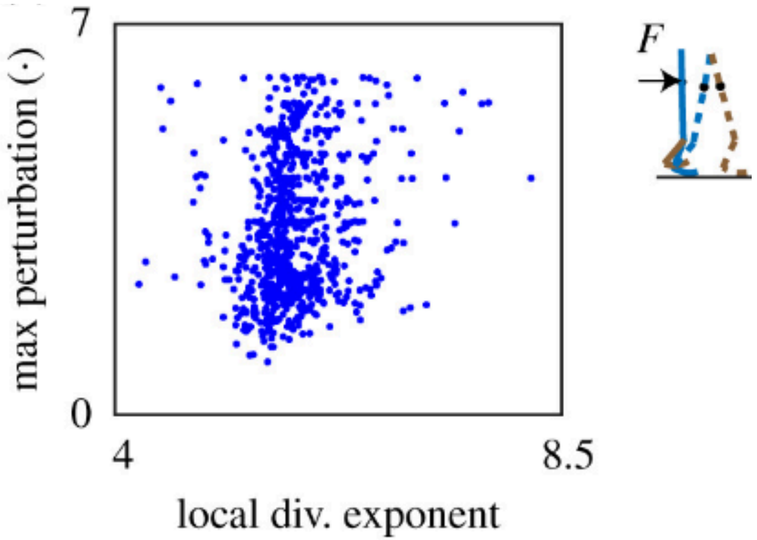


Bruijn et al 2012

Results model



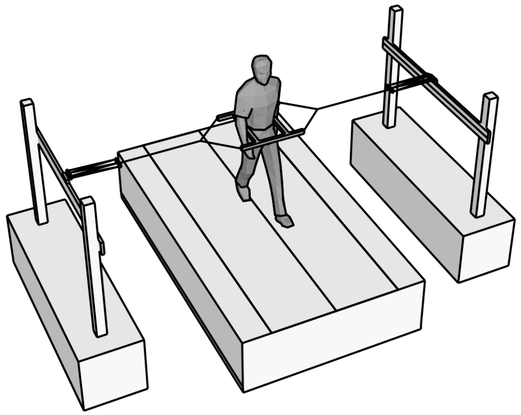




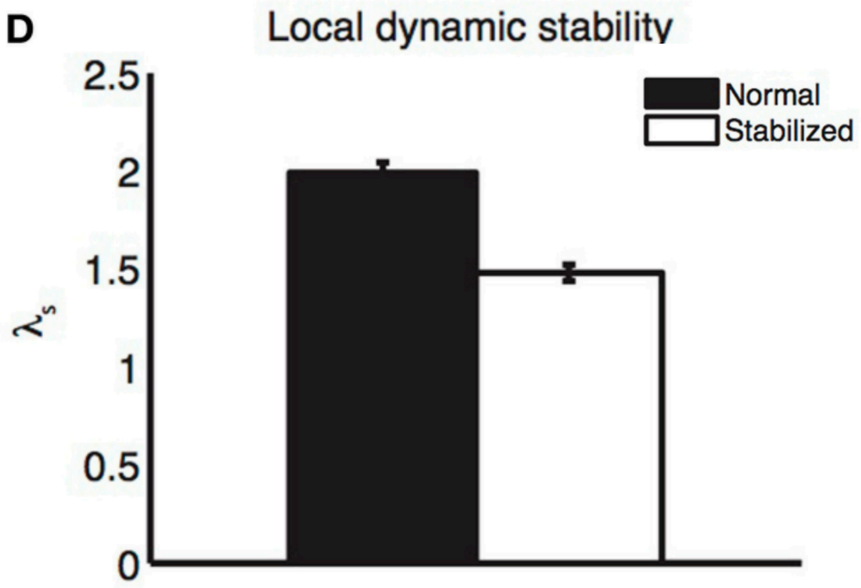
Jin et al 2021

Human experimental studies

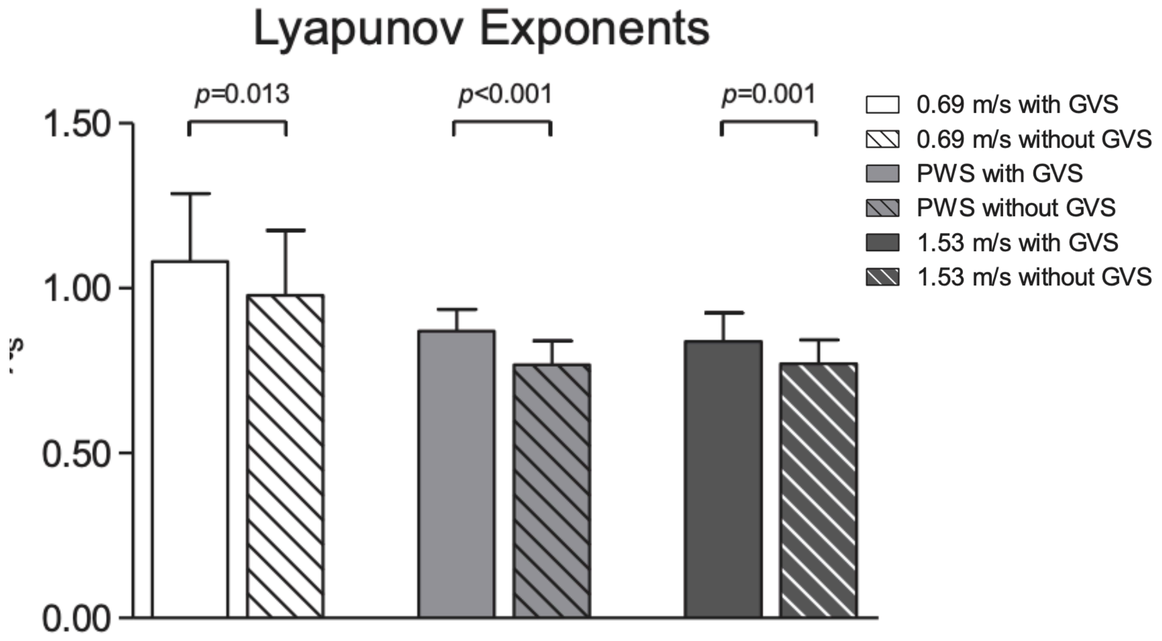
- Create known (un)stable situation
- calculate local divergence exponent



Results human experimental studies



Bruijn et al 2015



Van Schooten et al 2013

Human Cohort studies

- Compare know ‘stable’ group to known ‘unstable’ group
- Or compare people that fall to people that don’t fall
- There’s so much studies on these, that I’m not even going to mention examples
- Basically showing, it works

My Hopes right now

- You understand how I think about (gait) stability;
    - Steady state
    - Reactive
    - Proactive
- You understand the details of calculating local divergence exponents
    - Fixed embedding dimension and delay!
- You have seen that local divergence exponents most likely are a good measure of gait stability

Hands on can be found here