Name: Student number:

Coordination Dynamics:
Principles and Clinical Applications

Representative practice questions for interim exam 2014-2015

Please write on each sheet of paper your name and student number. The exam consists of several open questions, for which 20 points can be earned. Concise answers are highly appreciated and sufficient to earn the points. Note sections on pages 1 and 6 provide additional space to answer questions in case the provided space would be insufficient. Please note that erroneous passages in a lengthy answer may have adverse consequences in that they can lead to diminution of points you received for correct parts in the answer.

Good luck!

Notes: Question 3h) should not have been part of the practice exam, as it is not pertaining to study material for the interim exam of 2014-2015 (i.e., addressed in lecture 5)

Question 1: HKB Model

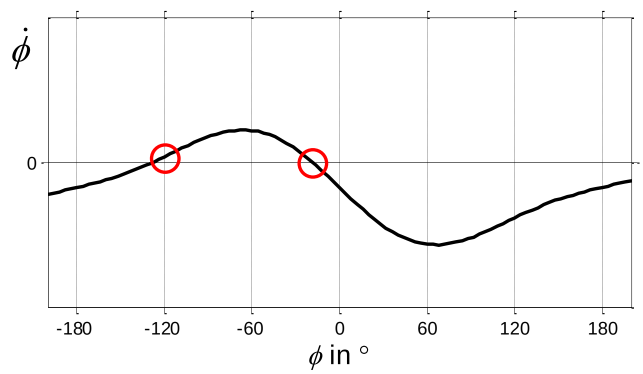
The Haken-Kelso-Bunz (HKB) model of coupled oscillators is one of the foundations of coordination dynamics, an empirically grounded theoretical framework that seeks to understand coordinated behavior in living things, using:

- potential $V(\phi) = -\Delta\omega\phi - a\cos(\phi) - b\cos(2\phi)$
- order parameter dynamics equation $\dot{\phi} = \Delta\omega - a\sin(\phi) - 2b\sin(2\phi) + \sqrt{Q}\zeta_t$

a) What is *relative coordination* and why can it not be captured with the standard HKB model (i.e., the HKB model with $\Delta\omega = 0$)? [**3 points**]

relative coordination is the result of the continuous struggle between the maintenance tendency (the oscillators prefers to oscillate at their own intrinsic frequency) and the magnet effect (the oscillators tend to oscillate at the same frequency). As a result of this competition, two oscillators with different intrinsic frequencies show complex behavior when coupled, most of which is not captured by the standard HKB model with $\Delta\omega = 0$, most notably the small shifts in the location of the attractors from 0 and 180 degrees and the possibility for phase wrapping and even metastability (loss of attractors, but with remnants of them).

b) The figure on the right depicts the order parameter dynamics $\dot{\phi}$ for b/a = 0.15 and a non-zero $\Delta\omega$. Designate the fixed points in this figure with open circles, and motivate whether they are stable or not. **[2 points]**



There are two fixed points in this figure, i.e., the zero crossings at phi = -20 degrees (approximately) and at phi = -125 degrees (approximately). The former is the stable one, as there is a strong driving force towards this fixed point for small deviations in phi (attractor, negative slope). In contrast, for the latter fixed point, the slope at the zero-crossing is positive, indicating that any small deviations away from the fixed points are repelled further away from this fixed point (unstable fixed point, repellor).

c) Is $\Delta\omega$ positive or negative in this figure? Briefly motivate your answer. [**1 point**]

negative, order parameter dynamics curve is offset below zero; at phi = 0, phidot is negative (curve is not shifted to the left!)

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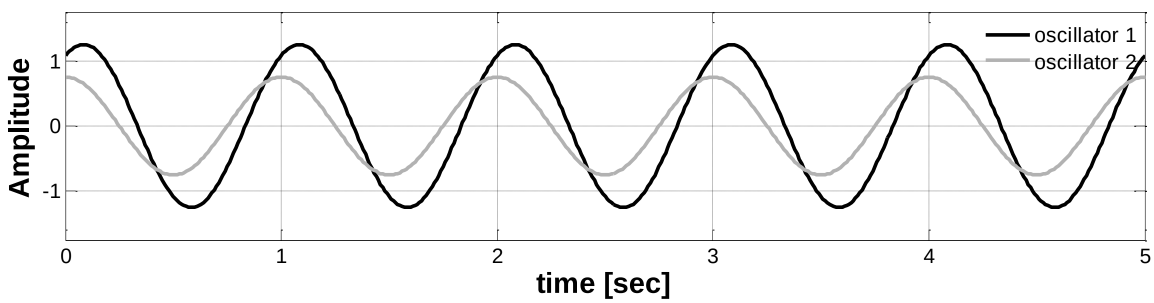
Question 2: relative phase

So far we have discussed two ways to determine relative phase to describe coordination between two oscillators.

- The first, the continuous relative phase $\varphi_{continuous,}$ was defined as the difference in phase evolution of two oscillators for each point in time, using $\varphi_{continuous} = \varphi_{oscillator1} - \varphi_{oscillator2}$.
- The second, the discrete relative phase $\varphi_{discrete}$, was defined as the time latency of one oscillator relative to the other divided by the oscillation period, evaluating coordination at only one point in each oscillation cycle (note that discrete relative phase is also known as the point estimate of relative phase). The discrete relative phase follows from $\varphi_{discrete,i} = 360°\cdot(t_{oscillator2,i}-t_{oscillator1,i})/(t_{oscillator1,i+1}-t_{oscillator1,i})$, where $t_{oscillator1,i}$ indicates the time of the i^{th} maximum in the cycle of oscillator 1 and $t_{oscillator2,i}$ corresponds to the moment of the i^{th} maximum in the cycle of oscillator 2.

In the figure below, trajectories of oscillators 1 and 2 are depicted. As you can see, there is a phase shift between the two oscillators. **Which oscillator is leading? [1 point]**

Oscillator 2 is leading, it arrives at its extrema earlier than oscillator 2 does (amplitude does not matter for phase lead/lag).



Which one of the following four options agrees with abovementioned definitions for $\varphi_{continuous}$ and $\varphi_{discrete}$? Briefly motivate your answer. [**2 points**].

a) $\varphi_{continuous} = 30°$ and $\varphi_{discrete} = 30°$

b) $\varphi_{continuous} = 30°$ and $\varphi_{discrete} = -30°$

c) $\varphi_{continuous} = -30°$ and $\varphi_{discrete} = 30°$

d) $\varphi_{continuous} = -30°$ and $\varphi_{discrete} = -30°$

b agrees with definitions. Continuous relative phase is defined at each time point. Let's examine the phases at t = 1. Oscillator 2 is at its maximum (for which we know that the phase angle is -360, i.e**., phase becomes negative as a function of time, each cycle -360 degrees), whereas oscillator 1 is near its maximum (so phase not yet -360 degrees, but let's say -330 degrees)*****.** Hence, continuous relative phase = -330 - - 360 = +30 degrees. Discrete relative phase was based on maxima. Around t = 1 one can see that oscillator 1 reaches its peak at about 1.1 sec and oscillator 2 at 1.0 sec. Oscillation period is 1 second. Hence, discrete relative phase is 360 x (1 - 1.1) / 1 = -36 degrees, so -30 degrees matches best.

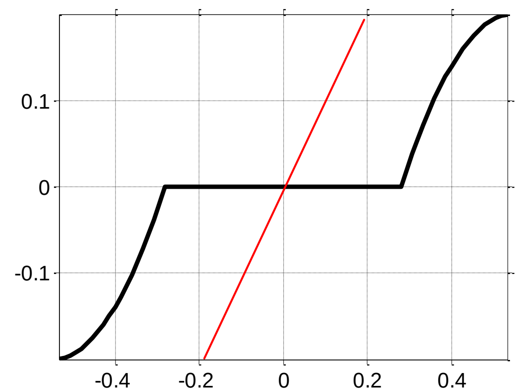
*** is dit omdat phase evolvement altijd negatief is?**

Question 3:

a) In Lecture 1 and associated literature, various examples of spontaneous pattern formation were given for systems composed of *many* interacting subsystems, among which the Rayleigh-Bénard system. Indicate the order and control parameters for this system. [**2 points**]

Control parameter: temperature gradient.
Order parameter: rotation frequency of convention rolls.

b) In Lecture 2 and associated literature, we have seen that two metronomes start ticking together when coupled, even though in uncoupled situations they tick at a slightly different frequency. This was indicated with a figure such as depicted here. Explain this figure by describing what the horizontal axis and the vertical axis entail. [**2 points**]



horizontal axis: deltaf: detuning, or frequency mismatch of two oscillators in *uncoupled* situations. Vertical axis: deltaF: frequency mismatch in *coupled* situation. synchronization when deltaF = 0.

c) Sketch in the figure the line for the no coupling situation. [**1 point**]

from [-0.2 -0.2] to [0.2 0.2]

d) When two oscillators are frequency locked, they also have a certain phase relation. This observation can happen by chance. How can you experimentally test whether the observed phase relation is a matter of chance or instead a genuine aspect of coupled oscillators? [**1 point**]

perturb the phase of one metronome and see if the relative phase returns to preperturbation values. Another option is to start both oscillators a number of times and see of the relative phase converges to similar values across attempts.

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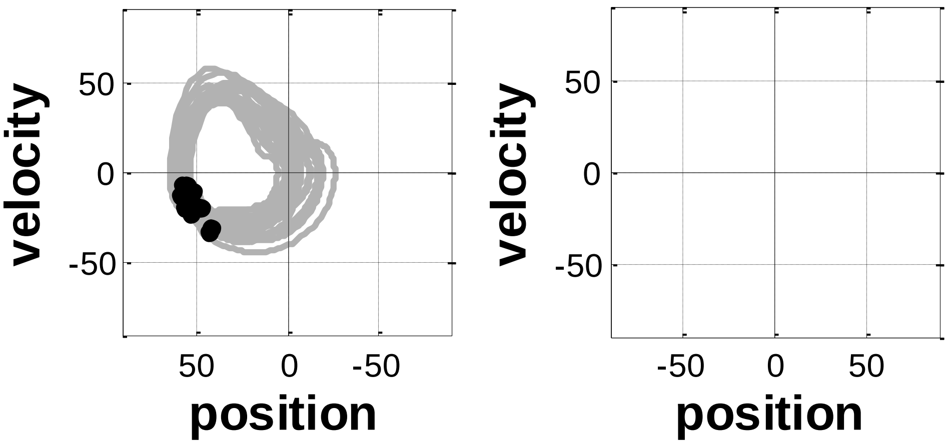
e) In Lecture 2 and Laboratory 1 syncopation experiments were introduced. What is syncopation? [**1 point**]

opposite of synchronization, thus to time a particular point in a movement cycle (peak flexion, clap) in between two external reference points (beats, claps, et cetera).

f) In Laboratory 1 and Computer Practical 1, rhythmic bimanual coordination was studied. In the picture below, you see the phase plane of the corresponding left hand (note the reverse x-axis) for one of the two windscreen wiping conditions (antiphase coordination between hands at a frequency paced by a metronome). Negative position values indicate that the wrist is in a more flexed (than neutral) orientation while positive position values indicate that the wrist is in a more extended (than neutral) orientation. Beep onsets are superimposed in the phase plane for the left hand with the black dots. Sketch a representative phase plane for the right hand for this windscreen wiping condition, including signs of anchoring. Briefly motivate your answer. [**3 points**]



This would be windscreen wiping to the left, as peak extensions of the left hand are timed to the beat, the phase plane is overall shifted towards a more extended posture, peak extension velocity is greater than peak flexion velocity and peak extension movement reversals are less spread out than peak flexion movement reversals. Hence, the representative phase plane, with signs of anchoring for this antiphase pattern for the right hand would include:
- shift of the phase plane towards an overall more flexed posture (negative)
- increased peak flexion velocity (e.g. -60) compared to peak extension velocity (+40)
- peak flexion excursions converge while peak extension excursions are more spread out.

g) In Lectures 3 and 4 and in computer practical 1, directional statistics was introduced. Directional statistics must be used when one is studying directional phenomena, such as relative phase time series. Give another example of time series for which directional statistics would be useful. [**1 point**]

Many examples possible, including circadian data (does this behavior occur at the same time every day, week, month?), direction (wind, navigation)

h) In Lecture 4 the notion of pathological regularity and health complexity was introduced, focusing on the ambiguous notion of time series variability. In statistics variability is defined as how spread out the data points are relative to the mean, quantified by the standard deviation. Is the standard deviation an informative descriptor of variability for the notion of pathological regularity versus healthy complexity? Motivate your answer. [**1 point**]

(CONTENT OF LECTURE 5, SO NOT PART OF THE PRACTICE EXAM!!!)

the essence of the notion of pathological regularity vs healthy complexity is that two time series can show very different dynamics, i.e., the temporal ordering of the data is quite periodic in case of pathologies and quite complex in healthy controls. The standard deviation does not capture time-dependent dynamics because it simply represents how spread out a time series is relative to the mean (tmporal order of those points does not matter). Thus, no, not informative with regard to the idea of pathological regularity and healthy complexity.

Notes: