Working instructions:

Examination of the granular material flow

PHYS-C0310 - Teknillisen fysiikan laboratoriotyöt

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Contents

1 Introduction

In this laboratory task we study the mass fluctuations of a sandpile grown on a circular plate. Such have been test systems of self-organized scale-free phenomena in physics since 1987, when Bak, Tang and Wiesenfeld presented this concept as a paradigm, for avalanching systems and $1/f$-noise and other scale-free phenomena in Nature [1] , [2] . The work consists of two parts. In the experimental part we consider the shape of the sandpile grown by sand deposition and the avalanches (outflow, and its fluctuations). The computational part is done simulating a sandpile by a simple cell automation.

2 Carrying out the experimental part

2.1 Test equipment

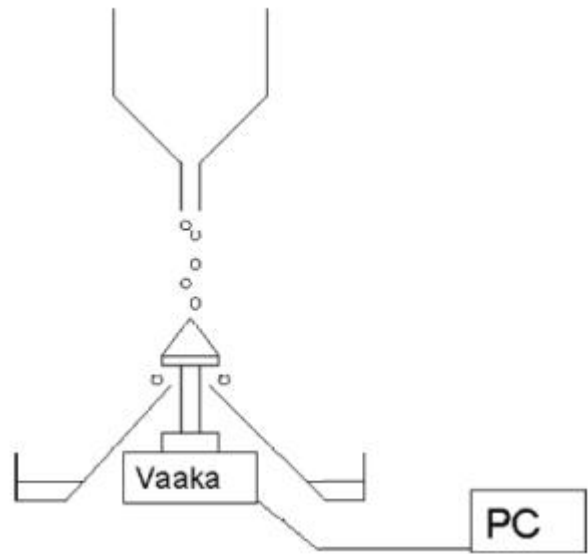Equipment used in the experimental part of the study is shown in Figure 1.

Figure 1: Test equipment

Sand is piled up from the top on a circular surface, which is attached to a weight measurement device. When at some point the sand pile becomes unstable, landslides are formed, and sand escapes. The scales are connected to a computer, and measurement program 'main.py' is used to save data into .dat file. The material used for the experiment is glass or iron beads. The glass beads are from 0,4 mm to 0,8 mm and the crushed iron is from 0,85 mm to 1,18 mm in diameter.

2.2 Tests and their performance

The test consists of the measurement of sand pile mass as a function of time, when new sand flows continuously at a constant rate. The same measurement is carried out with 2 different sized platforms to examine the effect of the size of the heap on its behavior and 2 different funnel nozzles to examine the effect of the flow rate.

2.2.1 Leveling and calibration of the equipment

The scales have a level bubble in a small round window beside the display. To level the balance, adjust the 4 Leveling Feet until the bubble is centered in the circle. Be sure the equipment is leveled each time its location is changed.

Measurements begin by calibration. To perform calibration press 'Cal' button on the scales. Attention: Do not disturb the balance during any calibration.

2.2.2 Steady flow under measurement

After the calibration the measurement is performed under a steady flow using the first plate. Measurement is as follows:

- The sand container is fixed above the system. Try to center it as closely as possible.

- Data collection is turned on (to a new file).

- The tank is filled with iron or glass sand. Sand begins to flow on the platform, and a pile starts to grow.

- When the pile has grown to a steady-state and landslides start, fine-tune the feeding so that the avalanches take place as uniformly as possible in all directions.

- When the measurement is running, assess visually using a ruler the pile height. Do this only for the largest plate.

- Funnel has to be refilled during the experiment a few times to get high amount of statistics.

- When enough data is obtained, the sand tank runs out, and the measurement is over. Stop the data collection, empty the pile, and test another plate or nozzle. Clean up at the end.

Note: If the nozzle becomes clogged during the measurement at any stage, it should be opened as soon as possible by applying a mechanical impulse to the tank.

2.3 Processing of the results

2.3.1 Determination of avalanche distribution

For the processing of mass data the assistant shares the matlab file virta.m for the flow test interpretation. File exploits reference [3] with a method for determining the sizes of avalanches. First, the first part of the curve is used to determine the flow rate of the sand. The avalanches are defined from the M (t) curve by the continuous passages of time during which the mass of the heap is continuously decreased. Any such period considered to be related to one avalanche, with the mass equal to the sum of the change computed from $M(t) - M(t + \Delta t)$ and the flow $j\Delta t$ during the avalanche.

Instructions for the determination of avalanches:

- Copy virta.m together with the result files from the measurement and open it with, for example, Matlab M-File Editor.

- Specify the names of the files to the relevant locations (use importdata ('XXX.txt ')).

- In the original result files there might be question marks after figures (it indicates that the weight reading was not stable during the measurement). These marks should be removed before importing date to Matlab.

- For the calculation of the flow rate one needs to determine the upper and lower indeses of the part where flow is steadily increasing. Choose these from the growth (of pile) phase.

- To search for avalanches one needs to determine an interval. Choose as the departure point a time when the equipment is running and as the end point when the sand is finished.

- The Matlab script outputs a figure to check, that everything works. The blue solid line depicts the pile mass as a function of time and the red dotted line illustrates the avalanche calculation process. Where the red dotted line is at zero or non-existing, avalanches are not counted.

When in accordance with the previous instructions you run the file "virta.m" in Matlab, you get out of the vector "Ava" in which each element corresponds to one landslide size. This information is used to determine the cumulative distribution of avalanches, as well as individual avalanche probability density.

To start the determination of avalanche distributions first find out which is the largest mass measured for a landslide that occurred (see. Matlab command "max"). The mass-axis from zero to the maximum value is subdivided into suitably sized intervals (equal intervals are not necessarily the best idea): try the manner in which you make the distribution the most sensible-looking. **Hint**: if you want to get good probability density function in loglog scale you should choose bin edges uniformly distributed in log scale. One can check the bin choice by plotting a histogram where the height of the columns correspond to the number of avalanches within each interval. The heights must be comparable to each other and there should be as few empty bins as possible.

The cumulative distribution at point m means the probability that the mass of an avalanche to occur is greater than m. Thus, for each of the discrete values compute the number of avalanches that have a larger mass, and divide it with the number of all avalanches (possibly useful commands: "histc", "cumsum").

The probability density for avalanches again is calculated for each interval (of avalanche masses) by computing the number of avalanches for the interval and dividing by its length. The result is assigned a value equal to the average of the avalanche masses in the interval. This is normalized then, so that distribution obtained is the distribution function for avalanches that take place when one mass unit is added to the pile. In practice, therefore, the distribution will be normalized (divided) by the mass flow during the measurement.

- **Example of probability density:** In the interval of masses from 5 to 10 there are 3 events, with masses 6, 7 and 9. The number of avalanches per unit interval is $3/(10 - 5) = 0.6$, and the average mass becomes $(6 + 7 + 9)/3 \approx 7.33$. There are 100 measurement points and the mass flow is 3 between each consecutive point. Thus the $p(m)$ gets assigned for the value $p(7.33) = 0.6/(100 * 3) = 0.002$.

The distributions should be presented in the report using both linear and logarithmic scales. In cases where avalanche probability density (or part of it) seems linear on a log-log scale fit a line ("slope") to that using the least squares method. The command "polyfit" may be beneficial here. The fit results in two parameters that equal to the prefactor of the "power-law" and the exponent $p(m) = Am^{-\alpha}$. What are these α ja A? Compare this fitted distribution by plotting the fit with the measured one with both logarithmic and linear scales. If you need to exclude some values from the fit, explain your reasoning.

2.3.2 Calculation of angles of repose

From the observed maximum height of the pile calculate an estimate for the critical angle θ_m at which the sand pile becomes unstable leading to an avalanche. Additionally, making an assumption that hips have conical shapes, calculate the angle of repose θ_r at which the progress of the avalanche stops. Knowing max height of the pile, mass of the pile and typical size of the avalanche it should be easy to do. Calculate also the difference between these two angles $\delta = \theta_m - \theta_r$.

3 Computational part

3.1 Calculation Model

The model used for the theoretical part is a slightly modified version of the two-dimensional one from Reference 2, a so-called Cellular Automaton (CA).The basic variable is the sand pile height matrix $h_{i,j}$, which describes the height profile of the pile (height h at location (i, j)). For symmetry reasons

one quarter of the plate is described. The height variable can take arbitrarily values inside the radius R, $(i^2 + j^2 \leq R^2)$ and is zero outside $(i^2 + j^2 > R^2)$. Simulation proceeds as follows:

- At the beginning of each simulation time step one grain of sand is added at a random location.

$$h_{i,j} \longrightarrow h_{i,j} + 1. \tag{1}$$

- From the height matrix one then calculates the matrix of local slopes.

$$\sigma_{i,j} = -(h_{i+1,j} + h_{i,j+1} - 2h_{i,j}) \tag{2}$$

- When the value of the local slope exceeds the critical slope, one grain is moved in the positive direction of the x-axis and one of the positive y-axis

$$\sigma_{i,j} > \sigma_c \Rightarrow \begin{cases} h_{i,j}, & \longrightarrow h_{i,j} - 2 \\ h_{i+1,j}, & \longrightarrow h_{i+1,j} + 1 \\ h_{i,j+1}, & \longrightarrow h_{i,j+1} + 1 \end{cases} \tag{3}$$

such that if one or both of the locations is outside of the radius R the grain is removed.

- This rule is applied everywhere until the pile is stabilized $\forall \sigma_{i,j} \leq \sigma_c$. After this the pile mass is stored, and a new grain is dropped.

The main result here, as in the experimental part, is the pile mass as a function of time and the resulting avalanche distribution.

3.2   The execution of simulations

This requires a Matlab file from the assistant. Start to use the code by "playing" such as: Try the effect of various parameters running short simulations. Adjustable parameters of the simulation are the plate size R and the critical slope σ_c. You may also vary the number of time-steps, or dropped particles. Both simulations must be at least 100 000 time-steps, in order to collect sufficient statistics for the event distribution.

3.3   Obtaining the avalanche distribution

Avalanche probability distribution function for a given mass $p(M)$ is defined as in the experimental section as the probability that in a given time interval happens an avalanche with size M (mass input per time unit is one). For each time step when the $M(t)$ has not simply grown by one it is clear that one avalanche has happened, with the mass following in a straightforward fashion. This is how the code calculates the events and as in the experimental part the size is stored as an element in a vector "ava". The cumulative distribution of avalanches, as well as the calculation of the probability density is performed in the same manner as before.

4 Report instructions

The first version of the report should be return during three weeks from the exercise. Assistant will grade the first version (0-10), give a feedback to the student, after which the student can improve (in two weeks time) the report, which will be then evaluated again. The final grade will be the average of the first and second version of the report.

4.1 Introduction

Explain briefly what self-organizing criticality is and what interesting physics this project contains. How is self-organizing criticality associated with sand piles? Check references [1] and [2] to support you. You may also take advantage of Wikipedia for writing an introduction. A cursory review is enough.

4.2 Methodology

A short but precise description of the testing apparatus, as well as the CA model. Draw an image of the experimental apparatus. Describe the CA model and explain what is the probability distribution of locations where the grains are deposited (see the Matlab code for this).

4.3 Results

For each experiment and the simulation show by figures

- Pile mass as a function of time (to illustrate the avalanche determination). Select a time interval so that the figure illustrates well the behavior in the experiment or in the simulation.

- The cumulative avalanche distribution and the probability density distribution, both on linear and logarithmic scales. For those cases where you have done a log-log fit illustrate in the same plot the fit(s). The fit parameters (power-law exponent in particular) are to be shown in the text

Comment and discuss the results, in particular the following issues:

- How the size of the plate and nozzle size affect the pile behavior, and why? Reflections on the topic can be found in references [3] and [4]. Analyze values of critical angle and angle of repose that you got. Does the pile behavior consistent with reference [4] explanations ?

- How reliable are the results of the tests?

- To what extent simulation and real pile you think are similar to each other? Justify your opinion.

4.4   Conclusions and summary

Tell us briefly what was studied, which processes and what kind of results were obtained. What did you learn? And what else could one do to learn more? Could one, for example, improve the experiments or simulations or could you think of any systems in Nature where self-organized criticality would be interesting and relevant?

References

[1] P. Bak, C. Tang, K. Wiesenfeld, Phys. Rev. Lett. 59, 381-384 (1987)

[2] P. Bak, C. Tang, K. Wiesenfeld, Phys. Rev. A 38, 364-375 (1988)

[3] N. Yoshioka, Earth Planets Space 55, 283-289 (2003)

[4] S. R. Nagel, Rev. Mod. Phys. 64, 321-325 (1992)