# SMART>SOS – a Vertigo collaboration by Tim Otto Roth & Bio4Comp

*SMART>SOS* is one of the 10 winning projects of the new VERTIGO STARTS initiative supported by the European Commission's Horizon 2020 program. Tim Otto Roth is developing together with Bio4Comp researchers from Dresden, Chemnitz (both Germany), Lund and Kalmar (both Sweden) a sound and video installation revealing the new paradigm of bio computation: a sub-sub-microbiological machinery based on tube like protein polymers, the so called microtubules.

## Biomolecules in a labyrinth – a kind of modified marble run

Bio4Comp developed a sophisticated mechanism to create a bio computer: It uses tube like molecules moving in a special labyrinth like nano structure edged in silicon dioxide. Essentially this network structure is designed to solve a so called subset problem. Bio4Comp's solution of this NP complete mathematical problem can be compared to a kind of marble run with agents passing a pyramid like structure of joints.
Although the marble balls turn randomly left or right at the split joints, the distribution of the balls at the outputs represent a certain pattern due to the geometry of the network of split and cross joints.

## Bringing feedback and interaction in

*SMART>SOS* also uses a network structure of split and cross joints, but it adds further components bringing feedback and even a kind of interaction in. The recursive concept is expressed especially by its ring like topology:

- The essential component of the circular logic is to link the units by a kind of feedback: Every unit gets an input from the left or the right neighbour and passes the agents at split joints either to the right or left neighbours.
- The supply structure for the agents in the centre plays also a special role. The shape looking like a circular saw blade triggers a circular motion of the agents and feeds them accidentally into the outer ring structure. The number and the position of the connections between the reservoir and the network results in different concentrations of the agents.
- Last but not least, a kind of interaction between the bio-molecular agents is added designing a kind of dead end at the unit combining a cross and split joints. This dead end causes some of the microtubules coming from one direction do get stuck. Consequently, they obstruct the passage for the microtubules coming from the other direction causing some of them even to go

into solution. By that way a kind of rudimentary conditional logic gate is created.

## A residency in five labs in Germany and Sweden

According the work plan Tim Otto Roth visits the Bio4comp research groups for several times:

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| 12.09.–13.09.2017 | Bio4Comp Workshop in Dresden |
| 14.09.–22.09.2017 | Dresden |
| 23.10.–27.10.2017 | Chemnitz |
| 13.11.–14.11.2017 | Lund |
| 15.11.–16.11.2017 | Kalmar |

The kick-off for *SMART>SOS* was the Bio4Comp workshop in mid-September 2017 in Dresden, presenting the project to the entire consortium. A quite sustained discussion of the conceptual parts of the project was followed by an extended meeting with Dan Nicolau Jr. (Molecular Sense Ltd, Oxford, UK) and Hillel Kugler (Bar-Ilan University, Israel). The particular work started thereafter in the Diez Lab at TU Dresden together with Till Korten: Till and Tim tested the ring-like network topology with 15 interconnected units in extended Matlab simulations, which helped to optimize the fluidic structure and to test new supplements. 30 "detector" zones were added to measure the transit of agents. These detectors help to analyse the behaviour and are later important for the sonification.

## Producing the first circuit

At the end of October the design was finally realized as nano structures in silicon by the E-Beam Lithography group lead by Danny Reuter at Fraunhofer ENAS in Chemnitz. In the cleanroom the whole processing chain was executed by the artist thanks to the great introduction by Georg Heldt: Coating the silicon waver, exposing it to the electron beam and developing it after. Finally, wavers were dry edged resulting in nano-structures with channels of a maximum width of just 1 micrometre edged into silicon dioxide.

Immediately after the structures were tested in Dresden. Till Korten developed a sophisticated procedure to treat the structures biochemically. Finally, the first images in the fluorescence microscope revealed that the structures not only work, but the agents even revealed a less biased behaviour then predicted in the simulations. In total, 10 different nano structures scaled to three different sizes were examined. Beside the big ring like topology also a trio of three interacting

substructures was created. The records of the microscope image series are the basis for further analysis. Finally, this footage will feed the video and sound installation.

Further stations of the residency were lab stays in Sweden with Frida Lindberg at Nano Lund and with the team of Alf Månsson at Linnaeus University in Kalmar getting acquainted with actin filaments as another molecular agent. A visit in the 3d-litography lab at Fraunhofer ISC in Würzburg (Germany) complemented the residency.

## Analysis

Microtubules do have a diameter of just 20-30 nanometres, which is much below of the wavelength of visible light ending at 390nm. This means that in a normal optical microscope the tubular molecules are simply invisible. This is why the microtubules are tagged with a fluorescent marker, so they become visible excited with UV light and can be recorded with a high sensitive video detector recording in our case b/w images of 512 by 512 pixels.
The simplest form to get a first impression of the behaviour of the molecular agents is to animate the sequence of images recorded every two seconds. *SMART>SOS* uses also such a time-lapse as central floor projection refined by its colouring. Here the colours yellow and blue highlight the dynamic and static part of the imagery.

A heat map allows to get a rudimentary impression of the system's behaviour at one glance. It is a kind of long-time exposure integrating the whole image series to one picture using a special trick: Not the raw single images are integrated but the difference images of two subsequent frames. This image subtraction allows to record only the changes in the image sequences speaking the moving parts.
This is why the difference images are of importance to measure the flux of the agents, as they filter out for instance agents, which are simply stuck in the channels. By a special processing with a red and blue colour map the animated series of difference images get a particular look viewed with anaglyphic glasses: The blue regions marking the agents seem to fly over a moving background.
The difference images are also used for the quantitative analysis of the agent's flux. This analysis focusses 30 zones measuring the changing brightness of pixels at the two exits of the 15 "logic units". The resulting series of numbers registering the pixels hits in the zones are the basis for a further mathematical analysis.

## The Artwork

SMART>SOS is a sound and video installation translating the process of sub-sub-microbiological nano-computation into a pending light and sound sculpture and two video projections. The star like structure (Ø = 400cm) of 30 illuminated speakers hanging over the visitors echoes visually the nano structure especially designed for the project but also acoustically: The flux of agents in the nano structure you see projected onto the floor is translated into modifications of filtered noise oscillating between TV noise and whispering wind at varying pitches. Every speaker is linked to a certain area of the nano structure. If agents pass that area the related loudspeaker lights up in a pastel like colour corresponding to the played frequency.

The image series projected on the floor is a sequence of fluorescence microscope images scaled by the factor of 20.000. Here you can follow the flux of the yellow coloured worm like organic molecules meandering over the bluish ground of the nano structure. The pixelated image projection vis a vis on the wall shows the corresponding difference image, which is used for the image analysis. This image series driving the activity of the loudspeakers is rendered with a particular colour-map. Wearing red-cyan glasses the red noise changes to the background and separates the blue active zones. The floor projection remains more or less unchanged with the glasses.

This image noise inspired conceptually the translation of the data into sound. The basis of the composition is white noise, which everybody knows from old TVs. This noise is filtered in a certain frequency range, which is varied by the base frequency and the width of the frequency band. The base frequency changes according to the activity in the corresponding area.