Rhythm Apparatus For the Overhead Projector: a Metaphorical Device

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Abstract: The rhythm apparatus for the overhead projector is a robotic device that can be used to demonstrate core concepts of the theory of embodied cognition. At the same time, it is also an instrument for audiovisual performances. Combining the communication of scientific insight with amusement and entertainment, it stands in the tradition of philosophical toys. Such a device is introduced here and used to illustrate, in a step-by-step manner, principles of embodied cognition: emergence and the interplay of brain, body and environment.

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1. Introduction

In this paper I present a robotic device for demonstrating core concepts of the theory of embodied cognition. At the same time this robotic device is used as an instrument for an audio-visual lecture and performance using an overhead projector. It can be seen in the tradition of philosophical toys (Wade 2004) because it is designed to experimentally show scientific insight while at the same time providing popular amusement through a play of shadow, light and sound. The presented work also relates to contemporary artistic expressions using the overhead projector as they have, for example, been featured at the art of the overhead festival in 2005 and 2009 (Hilfling and Gansing 2005, 2009).

1.1. Background: embodied cognition

The core claim of embodied cognition is that intelligent behavior in biological systems results from real-time dynamics and interaction between nervous system, body and environment (Johnson 1987, Port and van Gelder 1995, Thelen and Smith 1996). While computational approaches to cognition focus on the brain as the central information processing device, the embodied cognition perspective denies this single cause explanation. Historically this paradigmatic shift in the understanding of cognition gained momentum in the 1980s with a focus on explaining the cognitive aspects of movement (Kelso, Schöner 1988, Schöner, Haken and Kelso 1986). Recently the field has moved to higher cognition explaining more complex behaviors such as spatial working memory (Johnson, Spencer and Schöner 2008), object recognition (Faubel and Schöner 2008) or spatial language (Lipinski et al 2006).

A brilliant example for the type of insight this paradigm shift away from single cause explanation offered is the work from Esther Thelen on the development of walking in young infants (Thelen 1984). Newborn babies show a stepping reflex when held upright on a support surface. This stepping reflex disappears after a few months of age only to re-appear when the infant has already learnt to walk. The single cause explanation for this interesting experimental observation was that some neural maturation process in the brain would inhibit this reflex and that later higher level control would allow it to re-appear (McGraw 1943). This explanation was accepted for almost 40 years until it was challenged by Esther Thelen through a simple but insightful experiment. She put babies that had just lost their stepping reflex into a water basin. Relieved from the weight of their heavy legs in the water the stepping reflex re-appeared. Thelen argued that the disappearing of the stepping reflex was not the result of brain maturation but the result of gravity acting on the babies legs. In the early ages of development babies go through an impressive gain of weight, within three month they almost double their weight. Having to move their chubby heavy legs, babies naturally exercise and build up muscles. These muscles are prerequisite for babies to learn to walk (Thelen 1984). Only once they start walking, the stepping reflex re-appears as a result of training their muscles. In order to learn to walk and to make the first voluntary steps, losing the stepping reflex seems to be crucial and part of a developmental and intelligent learning process. Here 'intelligence' is as much to be found in fat legs as in the developing brain.

1.2. A robotic device as philosophical toy

The term philosophical toy was used in the 19th century to designate technical devices that provided scientific insight while at the same time providing amusement and entertainment (Wade 2004). Typically such devices were dealing with perceptual effects, and many are predecessors of today's cinema, such as for example the *Thaumatrope* or the *Phenakistoscope* (see Figure 1).

Fig. 1. The first three images, a *Thaumatrop*: two images, flowers and a vase, are fused into a single image by quickly spinning the disc. The last picture shows a *Phenakistoscope* disc by E. Muybridge that animates a dancing couple when put in rotation and watched through the slits in front of a mirror.

The robotic device I propose relates to philosophical toys in that a real-time animation is created with an overhead projector. The projection shows the shadow of the apparatus, its moving motors and legs (see Figure 2 for an overview of the setup). It does not demonstrate a visual or psychophysical effect. Instead it operates on a more abstract level and makes a theoretic concept comprehensible by using visual and auditive effects. The idea of the rhythm apparatus for the overhead projector is to demonstrate the interdependence of brain, body and environment. Similar to a biological organism there are three subsystems: An analog electronic controller, motors with legs and the environment. The analog electronic controller was developed by Hasslacher and Tilden (1995) and is inspired by simple neural networks that model central pattern generators (Bässler 1986). The minimalist electronic controller uses only 12 basic electronic components. The structure of the motors and legs is equally minimalist, just simple dc-gearbox motors with sticks out of acrylic glass as legs. The design is chosen to render an interesting projection that resembles more a machine than an organism. This is to underline that the device is clearly an abstraction of any living organism and that the apparatus operates on a metaphorical level to make key insights of embodiment accessible.

1.3. Overview

The paper is organized following the key concepts of embodiment that can be demonstrated with the apparatus.

- How structured patterns emerge out of the interaction of simple units.
- That functional modularity fails to account for the interaction of subsystems.
- How everything matters: the nervous system, the body, the environment and their real-time interaction.

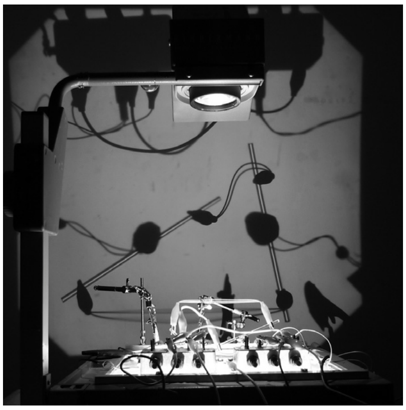

Fig. 2. Overview of the full setup: in the foreground is actual device on the overhead projector. The background shows the image that is produced through the projection.

2. The core circuit – emergence

Emergence signifies the property of a system to produce new structures out of the interplay of its constituents. Importantly the constituents alone cannot produce such structures and the new quality can only result from the interplay. This property can be paraphrased with the whole being greater than the sum of its parts.

In case of the electronic circuit, this new property is a pattern that only appears when the constituents, simple units – resistor-capacitor pairs coupled to an inverter (see Figure 3.a) – are connected into a loop. Each basic unit alone only acts as a change detector for rising activation at its input. Only when there is significant change of the input voltage an output signal is produced and the duration of the output signal is independent of the length of the input signal. The behavior in time of such a basic unit (see Figure 3.b) is similar to a biological neuron with two functional aspects: First a neuron only produces a spiking output when stimulated to a sufficient level (Abbott and Dayan 2001). Second, a neuron adapts to its input: on constant input it stops producing output spikes. The latter property we experience for example when we are exposed to a bad smell: even though the concentration of the molecules producing the odor is constant, after some time we do not smell it anymore (Cometto and Cain 1995). Similarly vision depends on eye movement: we see only because our eyes are in constant movement. We saccade three times a second and make tiny micro-saccades when fixating on an object. If the eye movement is stopped, our vision fades (Martinez et al. 2006).

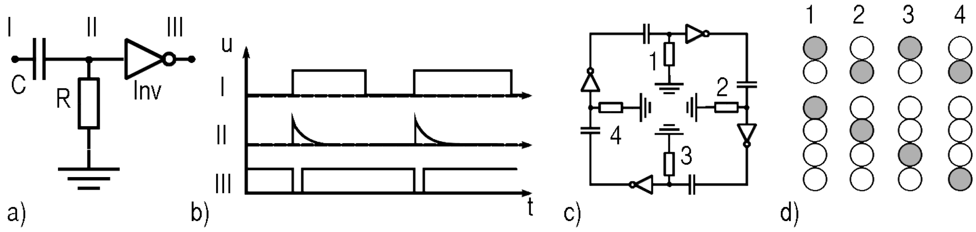

Fig. 3: a) The basic unit: a capacitor (C), a resistor (R) and the inverter (Inv). b) Temporal behavior of a basic unit: given an input signal at point I, the circuit follows the rise of the signal at point II, but then decays back to zero. At point III the output goes to zero at the rise of the input and then switches back when the decay goes below a threshold. A negative pulse is produced for every rising edge of the input. c) The microcore circuit: four basic units are connected into a loop. d) Illustration of the two dynamic patterns: the two top rows show the pattern with two traveling pulses, the four bottom rows the pattern with a single traveling pulse. Each dot represents the off (gray) or on (white) state of the output of a basic unit.

The emergent property is a pattern that appears when two or more of these basic units are connected into a loop. For the rhythm apparatus, I use four basic units (see Figure 3.c). This circuit, called the microcore, has been developed by Marc Tilden as a very simple model of a central pattern generator and was used to drive the leg movement of walking robots (Tilden 1994). The microcore can produce three different stable patterns: one static pattern where all units are off and two dynamic patterns, one with a single traveling pulse and one with two traveling pulses (see Figure 3.d)

2.1. Audiovisual presentation

The electronic circuits are built following a modular design that allows the reconfiguration of the network structure on the fly. Two basic units are assembled into one module, which is housed in a die cast aluminum enclosure with several interface connectors. On top are simple brass sticks that connect to the input and to the output of the basic units (see Figure 4). During a presentation it is possible to reconfigure the circuit using crocodile clips. As the whole setup is put on the overhead projector, the creation of a new connection is directly visible. The brass sticks are also used to connect to a set of strong light emitting diodes that visualize the pattern within the projection. When the overhead projector is dimmed, the light of the LEDs is clearly visible in the projection (see Figure 5).

Fig. 4. Die cast aluminum enclosure with brass sticks as interface connectors. On the front are potentiometers to modify internal parameters of the electronic circuit.

In addition to the brass sticks, a module has mini-jack audio connectors to directly connect to an active speaker or a mixing desk. This way the pattern is made audible in a straightforward way: By directly using the pattern to move the speaker membrane, a beat is created.

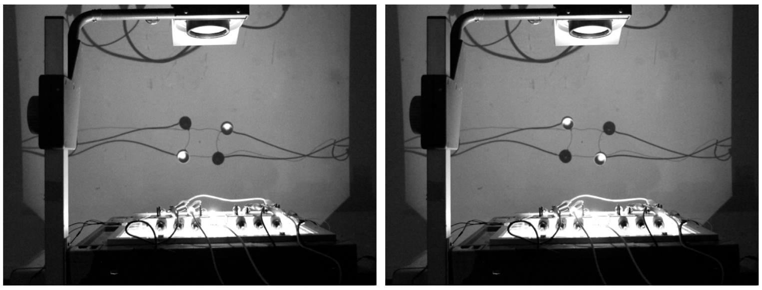

Fig. 5. Displaying the pattern with light emitting diodes on the overhead projector. The two frames show the dynamic activation pattern. In the left frame the outputs number 2 and 4 are active, in the next frame outputs number 1 and 3 are active.

3. Adding motors and legs – no functional modularity

Adding motors to the system illustrates two more important concepts of embodiment. First, to really understand the function of a complex system breaking it down into functional modules can be totally misleading. Attributing modular structures to a system is often tempting because it seems to simplify understanding, but when modules interact with other modules, this can fully alter the way they function. Second, dividing behavior into the chain of sense-plan-act processes is not the best description for behaving organisms. For example the processes of sensing acting and planning may be interdependent and intermingled.

When a motor is connected to the outputs of two neighboring basic units of the microcore, it receives alternating pulses from them. In theory this should produce an alternating movement. The motor should swing from left to right and then back. However this is not what happens when two motors are connected to the outputs of the four basic units. Instead the dynamic pattern disappears and both motors just rotate into a single direction without alternation or pattern.

With a modular perspective one might be tempted to conclude that the modular system is now broken and defunct. But a simple experiment reveals that it has actually gained an important property: it has become sensitive. When one adds legs to the motors, so that it is easy to interact with them with your own fingers, one realizes that if one stops both motors at the same time they will flip direction. The legs seem to feel the performers fingers, the motors behave as sensors.

This raises again the second point from above. If the same device that produces the movement also senses, does it really do it in the order of sense-plan-act? An analysis of the interaction of the motors with the electronics reveals that it is the specific combination of the electronic circuit with the motors that produces a behavior which includes sensing and acting or rather acting and sensing. The pattern disappears because the motors are directly connected to the electronics without an intermediate driver stage. As a matter of fact they directly influence the behavior of the electronic circuit. The inertia of the mechanical parts of the motor produces an opposing force to the current from the electronic circuit. Because every electric motor also functions as a generator, when it moves through an external force, such as inertia, it produces a current. The motors override the pattern of the microcore.

3.1. Audiovisual presentation

The motors are added by simply fixating them with a clay-like material onto the screen of the overhead projector. They are connected to a motor connector on each module. Once connected they immediately begin to rotate, and one sees the shadows of the legs rotating in the projection. The sound changes accordingly, as the motors are connected they become audible and one hears the sound of continuously rotating motors. Moving the finger into the projection to stop the motors causes them to flip direction, which again is audible as a beat. The device becomes an instrument that partly plays on its own.

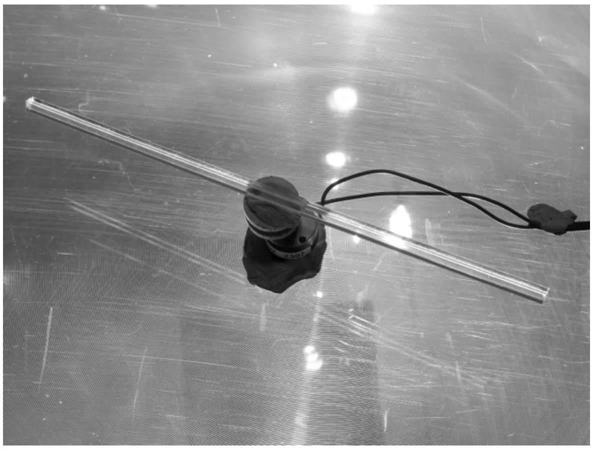

Fig. 6. The dc-gearbox motor with an acrylic glass stick as leg

4. Adding external structure – everything matters

The last lesson showcases how complex patterns result from the real-time dynamics and interaction of a simple controller, a body and the environment.

The environment here is simply created by introducing piezo pickups (Collins 2009) as obstacles for the legs. As the motors 'feel' these obstacles they reverse when touching them. The pattern re-appears as rhythmic movement. The rhythm itself can be modified by changing the positions of the piezo-pickups. When they are placed to constrain the movement the rhythm accelerates, and when there is more space the rhythm slows down. A second physical manipulation consists in adding rubber bands between the legs. Through the rubber band the motors provide mechanical feedback onto each other which stabilizes the rhythmic movement. A third manipulation modifies the internal parameters of the electronic circuit. By reducing the resistance of the resistance-capacitor pair, the timing and thus the rhythm may also be changed. A forth manipulation controls the degree of electrical feedback into the electronic circuit. When the feedback from the motors is reduced, the legs react less to the environment and follow more the internal pattern of the electronics.

4.1. Audiovisual presentation

Introducing the piezo-pickups modifies the behavior of the apparatus, and a regular rhythm re-appears. The pickups act as mechanical barrier but of course they also produce a sound. Using different materials, such as for example felt or paper, they can be tuned to sound lower or higher respectively. Adding the rubber bands introduces a new graphical element to the projection, and the rubber bands appear as thin moving lines in the projection of the overhead. As the rubber bands influence the movement of the motors the sound of the motors changes as well. In order to create more tonal variations a simple analog synthesizer can be connected to the output signals of the core electronic circuit so that it actually behaves as a sequencer.

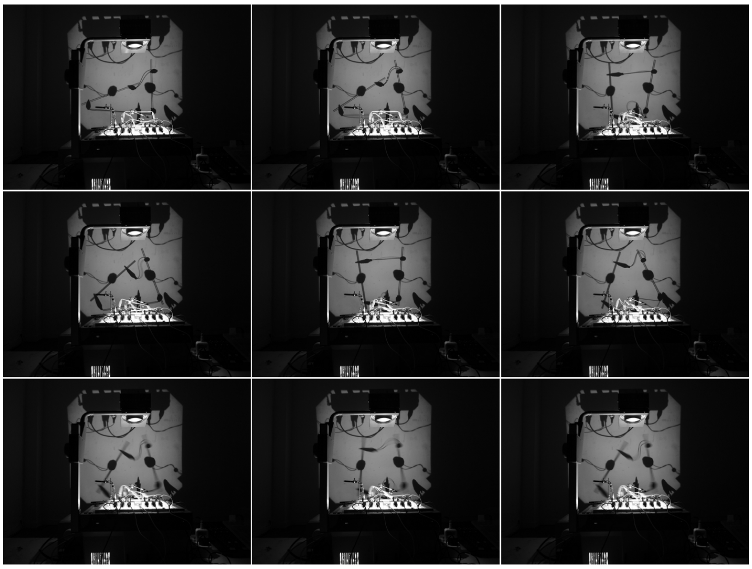

Fig. 7. Key frames of the final demonstration with moving legs, rubber bands between the legs and piezo pick-ups.

With all the parameters that can be modified on the fly, the overall demonstration turns into an audiovisual performance. Its varying beat patterns that are always in sync with the movement of the legs in the projection.

5. Summary and conclusion

Combining the didactic wish to convey a complex scientific topic with a format that may entertain and amuse the audience was once a standard approach in science referred to as philosophical toys. The rhythm apparatus for the overhead projector picks up this tradition to convey a scientific theory. It uses very simple analog electronics to create a behaving system that produces complex movement patterns that are interesting to look at and to hear to. The theory of embodied cognition offers an alternative approach to understanding human and animal cognition. In a step-by-step assembly of the apparatus, core insights about embodiment are conveyed by using the device as a metaphor for biological organisms. The metaphor lies in the fact that, analogous to living organisms, the interactions between subsystems rather than the subsystems themselves create a huge variety of new behaviors. Being far from as complex as any real living organism it however can provide a glimpse of how complex behavior can emerge.

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