KANN MAN THERMODYNAMIK VERSTEHEN?

Ein Modell figurativer Strukturen der Konzeptualisierung makroskopischer Prozesse

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Teil 1

ALEX UND CARATHEORORY

Zwei total verschiedene Arten, über thermische Prozesse zu sprechen, als Beispiele von vielen verschiedenen Möglichkeiten.

Was für Darstellungen lassen sich verstehen? Was bedeutet **Verstehen** überhaupt?

ALEX UND CARATHEORORY

KLEIN ALEX UND DIE KÄLTE…[a]	CARATHEORORY…[b]
On a winter day, when he was five years old, Alex came home from kindergarten. He talked to his grandmother about how the teacher had told them they should close the door or cold would come in. His grandmother wanted to know from Alex what cold was. He said that cold was a snowman. A snowman was very cold and if he hugged Alex, the boy would get cold too and could get sick. Alex and his grandmother were outside and decided to build a snowman. When his grandmother wanted to build a big one, Alex said that a big snowman would be so cold it could even kill young Alex. Alex thought it would be better to build a small snowman. 	*Zweites Axiom: In jeder beliebigen Umgebung eins vorgeschriebenen Anfangszustandes gibt es Zuztände, die durch adiabatische Zustandsänderungen nicht beliebig approximiert werden können.* *Pfaffsche Formen:* $$dS = \frac{\delta Q}{T}$$ $$dS = \frac{dU + pdV}{T}$$ *Starting from the existence of adiabatic surfaces for a thermodynamic system, we show, by coupling it to a perfect gas, that the absolute temperature is an integrating factor of the reversible heat input. The proof makes no use of the general theory of Pfaffians.*[c]

a. E. Sassi (2006): Private communication.
b. Caratheorory (1909): Untersuchungen über die Grundlagen der Thermodynamik. *Math. Ann.* **67**, 355–386.
c. Marshall T. W. (1978): A simplified version of Carathéodory thermodynamics. *AJP* **46**,136-137.

Teil 2

ANALYSE EINER WINTER GESCHICHTE

A small town called Little Hollow lay in a hollow surrounded by a high plain. People had settled in that place because small streams collected on the plain and flowed down into the hollow and through their town as a nice gentle river. This the people of Little Hollow liked a lot. But there was something they liked a lot less: Winters in Little Hollow were harsh.

As the last of the warmth of late Fall left the plain surrounding Little Hollow, cold found its way into the area and spread out. Because the plain was so wide, the cold of winter had to spread pretty thinly, so it was not all that cold up there. Moreover, even in the midst of winter, the Sun managed to send some warming rays onto the plain. The

snow that fell on the plain was not so cold either, but it was plenty, and the people of Little Hollow loved to go up to the plain for cross country skiing. The little kids went there to build beautiful snowmen.

But in Little Hollow, things were different. The cold of winter knew a good place where it could do its job much more easily of making everything and everybody cold. It could flow into the hollow where the town had been built. It could collect there and it knew it would not be driven out so easily by a little bit of wind as could happen on the plain. And the Sun could not reach the town that easily, also because of fog that often lay over Little Hollow and made everything gray. More and more cold could collect in Little Hollow, and it got colder and colder as the winter grew stronger. The temperature fell and fell.

The people of Little Hollow cursed winter and its cold. They knew that the cold would find its way into their homes if they were not careful to close windows and doors. The cold could even sneak in through tiny cracks between walls and windows, so the people had learned to build their homes well to make it hard for cold to flow in. Still, without the sophisticated and strong heaters in their homes, people knew they could never survive winter …

STORIES: TRADITIONAL MODEL

- Stories reflect a **form of human thought**. They have an underlying grammar (schema) that is used for understanding/thinking. Story grammar: A story sets up a problem initially; this problem is then elaborated in the middle and mediated/solved at the end (Egan 1986, 1988; Mandler 1984).
- Stories organize **affective meaning**. They are **explanatory narratives** that let us know **how to feel about the events** that make them up.
- Stories deal with **human affairs**.
- **Polarities** (binary opposites) are central to setting up the scene for a story. In our example, **COLD** is structured by the polarity **HELPER** <–> **DESTROYER**.

QUESTIONS

- Does **COLD** have a meaning as a **character of nature** in our stories?
- If so, **what kind of meaning** does it have?
- Can this meaning lead to **good formal science**?

THE WINTER STORY: COLD AS A CHARACTER

Actually, in our story **COLD** appears as a character having several clear and distinct properties:

- The character develops as a consequence of the **polarity HOT <—> COLD**.
- **Differences** of hot–cold are the driving force for the processes that let **COLD** act.
- Changes in **degrees** of **COLD** are the main manifestations of **COLD**.
- **COLD** is contained / **stored** in bodies.
- There can be **more or less COLD**.
- **COLD** can **flow** (sneak, force its way …).
- We can **obstruct** or help the flow of **COLD**.
- **COLD** is **powerful**. **COLD** is the **cause** of many other phenomena (freezing hands, cold homes, dry snow…).
- Heat can counteract / **balance COLD**.

The aspects of the **gestalt of cold** identified here are *quality/intensity*, *quantity/size*, and *force/power*. I call gestalts having this structure **Force Dynamic Gestalt**.

STORY SCHEMA AND CHARACTER SCHEMA: TWO PARALLEL STRUCTURES IN STORIES

Created by different **polarities**, we have two **parallel schematic structures** in our Winter Story:

1. **COLD** as an evil force: **Polarity of DESTROYER <—> HELPER** or **SUFFERING <—> WELL-BEING**
   - Initial tension
   - Elaboration, dilemma, goal, path
   - Mediation, balance, resolution

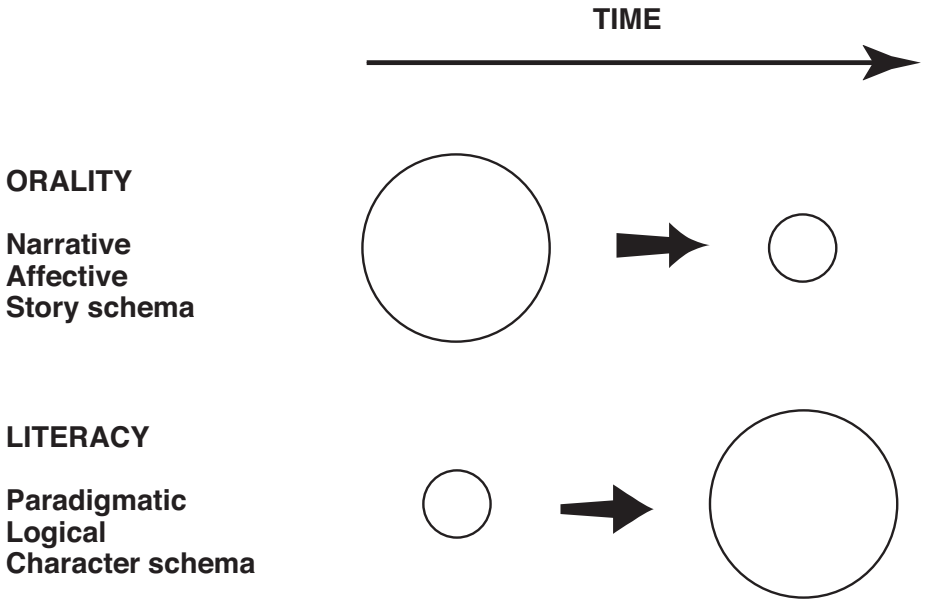
   —> leads to a story following the typical **story schema** (—> **affective meaning**)

2. **COLD** as a natural phenomenon: **Polarity of COLD <—> HOT**.
   - Difference between hot and cold as driving force
   - Quantity of cold, stored, flowing
   - Force/power of cold (influencing, causing…)

   —> creates the nature of a character in the story following the typical **character schema** (—> affective meaning that readily leads to **logical meaning**)

VOM KINDERGARTEN ZUR HOCHSCHULE

Ein Vorschlag für die Entwicklung von Story Schema und Character Schema im Laufe der Schule:



In einem Naturwissenschaftsunterricht kann im Lauf der Zeit das klassische Story Schema zugunsten des Charakter Schemas in den Hintergrund treten. Dadurch verstärkt sich logisches Verstehen gegenüber affektivem Verstehen (Fuchs, 2010b).

BEOBACHTUNGEN ZUR STRUKTUR VON GESCHICHTEN

- Es ist interessant zu sehen, dass das klassische Story Schema durch eine Polarität aufgebaut wird — genau wie das Charakter Schema.
- Eine Polarität wie **LEIDEN/SCHMERZ <—> WOHLERGEHEN/BEHAGEN** macht aus dem dahinter liegenden Phänomen auch wieder eine Force Dynamic Gestalt. Sollte zum Beispiel abstrakte Begriffe wie **LEIDEN, SCHMERZ, GESUNDHEIT…** zum Thema werden, würde man sie als Gestalten oder Charakter wie **KÄLTE** in einer Geschichte behandeln.

- Wir verstehen die Geschichte, weil wir die Polarität **LEIDEN/SCHMERZ <—> WOHLERGEHEN/BEHAGEN** verstehen.
- Wir verstehen Kälte, weil wir die Polarität **HEISS <—> KALT** verstehen.

- Zwischen affektivem und logischem Verstehen gibt es keinen unversöhnlichen Gegensatz.

Teil 3

DIE BEDEUTUNG VON EMBODIMENT

Die hier identifizierten Strukturen und Konzeptualisierungen werden in den kognitiven Wissenschaften **embodied** (körperbezogen, verkörperlicht) genannt. Hier sind drei Aspekte von **embodiment**:

Linguistische Aspekte von Embodiment

Eine biologische Sicht auf Embodiment

Philosophische Bedeutung von Embodiment

LINGUISTISCHE ASPEKTE VON EMBODIMENT

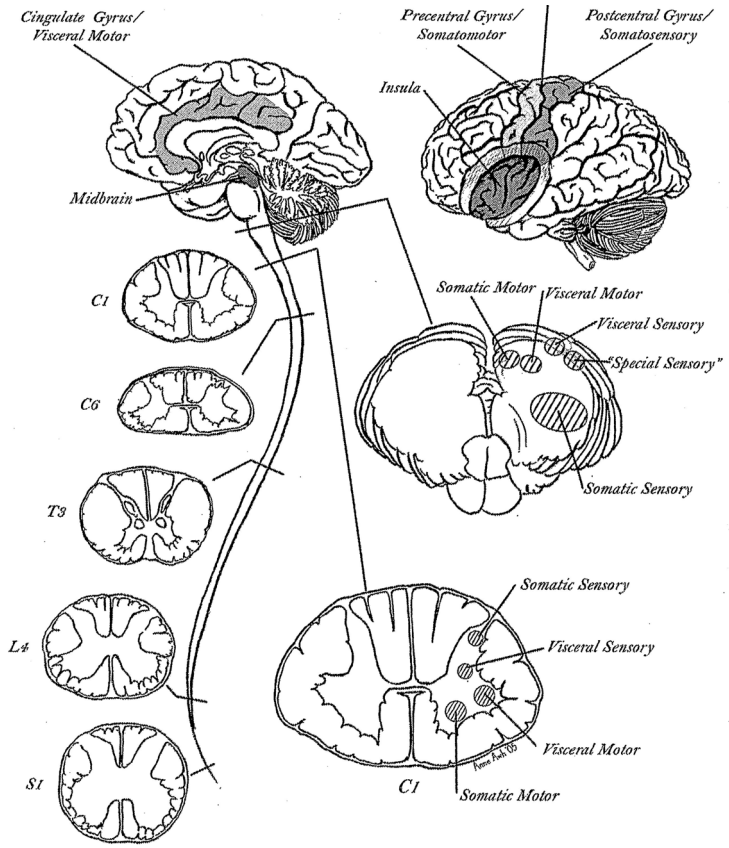
Die **kognitive Linguistik** behauptet, dass bestimmte in der Sprache sichtbare **linguistische Strukturen nicht zufällig** (oberflächlich) sind, sondern auf zugrundeliegende **Denktrukturen** schliessen lassen. Behauptungen…

- Sprache ist grösstenteils **figurativ**, also ist es auch das menschliche Denken (Gibbs, 1994).
- Ein Element des figurativen Verstehens sind **konzeptuelle Metaphern** (Lakoff and Johnson, 1980). Meatphern sind **Projektionen** der Struktur eines Quellgebietes auf ein Zielgebiet.
- Grundelemente des figurativen Verstehens sind **Vorstellungsschemas** (image schemas, Johnson (1987), Lakoff (1987), Hampe (2005)) wie hoch-tief, innen-aussen, Behälter, Substanz, Prozess, Pfad, Balance…
- Die Sprache der Kausalität ist die der **Force Dynamic Schemas** (Talmy, 2000).

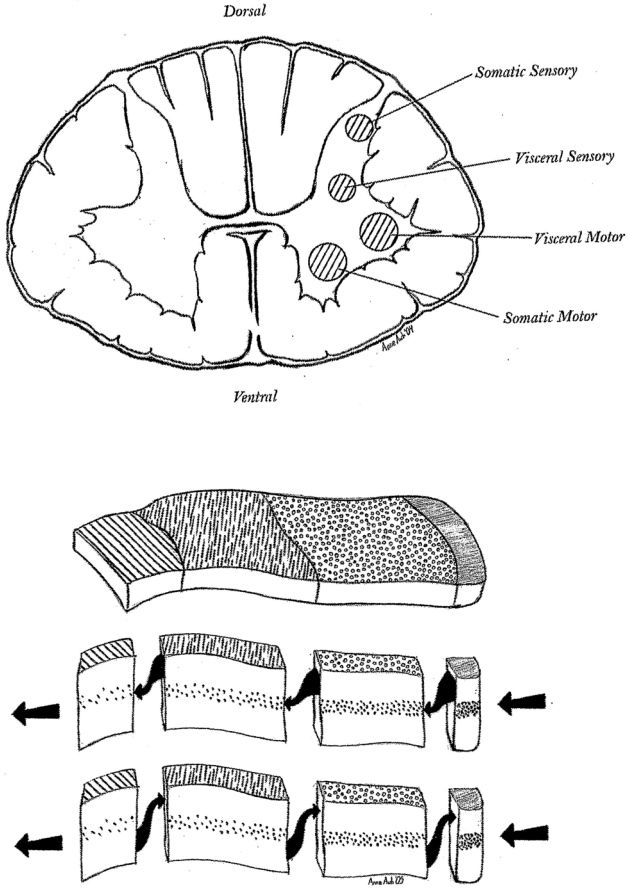
  EMBODIMENT THESE: Alle diese Schemas sind klar **embodied**. Sie entwickeln sich schon im Kleinkind durch die Wechselwirkung von Körper und Gehirn mit der Umwelt. Vorstellungsschemas führen zur einfachsten Strukturierung eines Quellgebietes.
- Eine Makrostuktur des figurativen Verstehens sind **Stories** oder **Narrative**.

FIGURATIVE SPRACHE heisst, dass Schemas als Figuren (Formen) des Denkens in der Sprache auftreten. Sprache ist nicht buchstäblich zu verstehen.

Eine Biologische Sicht auf Embodiment

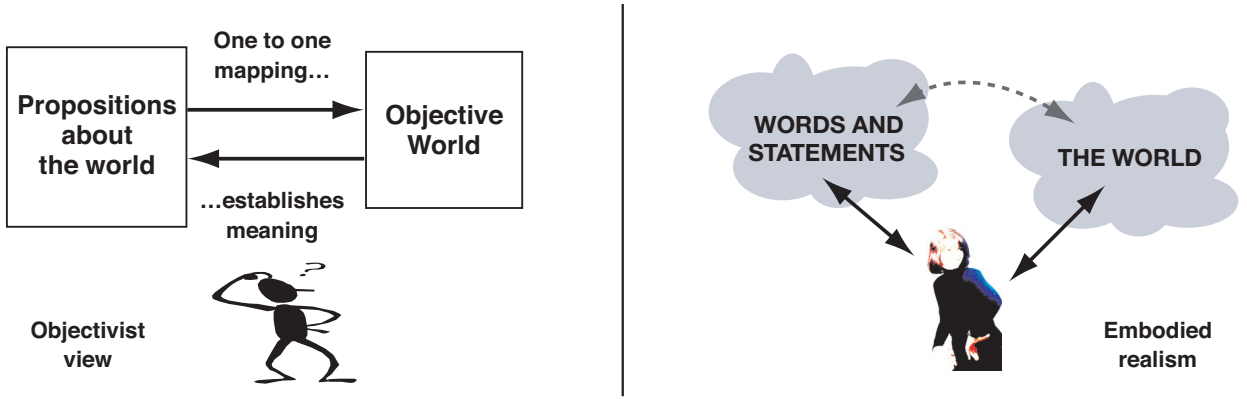


Tucker D. M. (2007): *Mind From Body.* Oxford University Press, Oxford, UK. p. 155, 156, 174.



Der Teil des Gehirns, der für das **Innere** des Körpers verantworlich ist, schiebt sich **zwischen** sensorische und motorische Teile des Gehirns.

PHILOSOPHISCHE BEDEUTUNG VON EMBODIMENT



Es gibt keine direkte eins-zu-eins Beziehung zwischen Wörtern (Aussagen) und der Welt. Der menschliche Körper mit seinem Gehirn tritt zwischen die Welt und die Wörter, die wir aussprechen. DIe Bedeutung der Wörter ergibt sich dadurch, dass sie sich auf die verkörperlichten figurativen Strukturen des menschlichen Geistes beziehen.

Unsere Aussagen sind nicht Darstellungen der Aussenwelt, sie sind **Darstellungen unserer Vorstellungen**. Bedeutung (Verständnis) ergibt sich, wenn ein Phänomen auf unsere verkörperlichten Vorstellungen (zurück)bezogen wird.

Frage: **Welcher Art sind unsere Vorstellungen von physikalischen Prozesse?**

Teil 4

FIGURATIVE STRUKTUREN IN DER PHYSIK: FORCE DYNAMIC GESTALT UND ANALOGIE

Gestalts of phenomena that have the potential to become rich concepts appear to be **differentiated** with the help of a few basic schematic structures, and the same schemas are applied to vastly different realms of experience. First among the **schematic structures** that are used recurrently are **quantity** or size, **quality** or intensity, and **power** or force.

If the same aspects are used to structure different phenomena, these become similar for us: we can employ **analogical reasoning**.

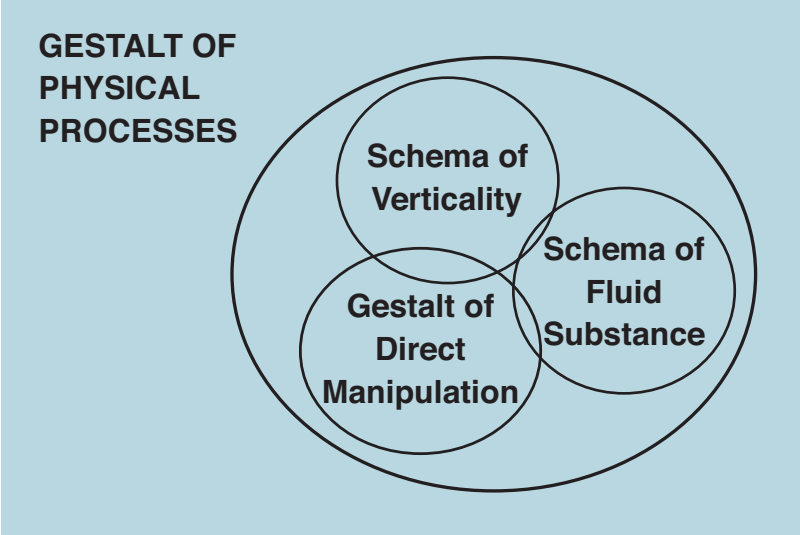
CONCEPTUAL METAPHORS IN THE WINTER STORY

METAPHORS	LINGUISTIC METAPHORIC EXPRESSIONS
COLD IS A (FLUID) SUBSTANCE	*The cold found its way into the area and spread out.* *Because the plain was so wide, the cold of winter had to spread pretty thinly,…* *It could flow into the hollow… it could collect there…* *The cold could even sneak in through tiny cracks between walls and windows…*
THE DEGREE OF COLD IS A (VERTICAL) SCALE	*Winters in Little Hollow were harsh.* *So it was not all that cold up there.* *And it got colder and colder as the winter grew stronger. The temperature fell and fell.* *When it had become terribly cold and the temperature was very, very low…*
COLD IS A POWERFUL AGENT	*The cold of winter knew a good place where it could do its job of making everything and everybody cold…* *It went into the snow lying on the ground to make it very cold as well and this made the snow drier and harder to work with.* *It knew it would not be driven out so easily by a little bit of wind…* *The fires in the furnaces had to work very hard to fight the cold.*

THE PHENOMENON OF COLD

Clearly, the gestalt of cold in the Winter Story has the same figurative structure. There is a **quantity** of cold, cold can be more or less **intense**, and cold has **power**. This is how the Experimenters of the Accademia del Cimento (Magalotti, 1667) explained their experiments.

I call experiential gestalts having these aspects **Force Dynamic Gestalts** (Fuchs, 2006). Physical processes are experienced as FDGs and conceptualized in this form:



RICH EXPERIENTIAL GESTALTS IN PHYSICS: FDG OF ELECTRICITY

Schemas	Linguistic expressions
Quantity (amount) *Container, Path*	The capacitor stores a lot of electricity Electricity (charge) flows through this connector
Polarity *Intensity, Level of…* *Level difference*	This body is strongly charged (weakly charged) The capacitor has been charged to a high level The difference of potentials is called voltage
Force or power *Agent and patient, causation*	Electricity drives this pump Electricity is used to…
Tension	The difference of intensities creates an electric tension
Balance	Voltages of the capacitors have finally equilibrated
Letting, hindering	The resistor obstructs the flow of charge

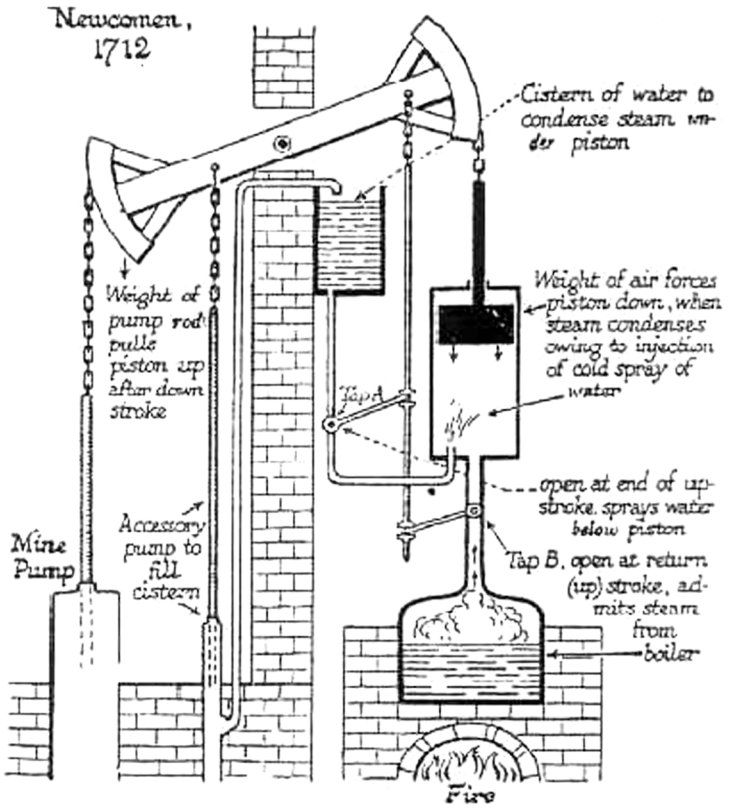
The basic perceptual function of **Figure-Ground Reversal** applies to physical phenomena as well. Example: a. Charge is draining from this element; b. This body is on a higher electric level. This may well be the root of the concept of **quantity of electricity** (if we take the notion of polarity, i.e., intensity, as given). (Fuchs, 2005)

THE FORCE DYNAMIC GESTALT OF HEAT

Sadi Carnot (1796-1832)

Réflexions sur la puissance motrice du feu (1824)

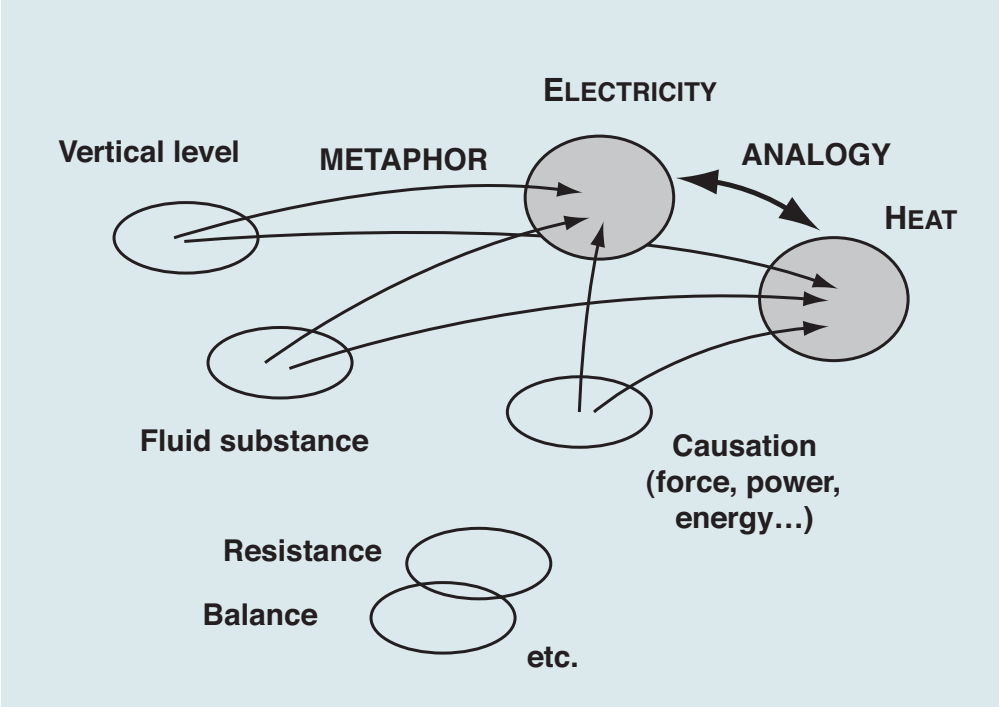
D'après les notions établies jusqu'à présent, on peut comparer avec assez de justesse la *puissance motrice de la chaleur* à celle d'une *chute d'eau* […]. La puissance motrice d'une chute d'eau dépend de sa hauteur et de la quantité du liquide; la puissance motrice de la chaleur dépend aussi de *la quantité de calorique* employé, et de ce qu'on pourrait nommer, de ce que nous appellerons en effet *la hauteur de sa chute*, c'est-à-dire de *la différence de température* des corps entre lesquels se fait l'échange du calorique.



DIAGRAMMATIC VIEW OF NEWCOMEN'S ATMOSPHERIC OR FIRE ENGINE (1712)

FORCE DYNAMIC GESTALT IN PHYSICS AND ANALOGICAL REASONING

If we use **the same schemas and metaphoric projections** to understand different phenomena, these **phenomena attain a degree of similarity** in our mind. This can be used in a form of **analogical reasoning** (analogy as structure mapping). (Fuchs, 2007)



Teil 5

MENGE, INTENSITÄT UND KRAFT DER WÄRME: EINE DYNAMISCHE THEORIE THERMISCHER PROZESSE

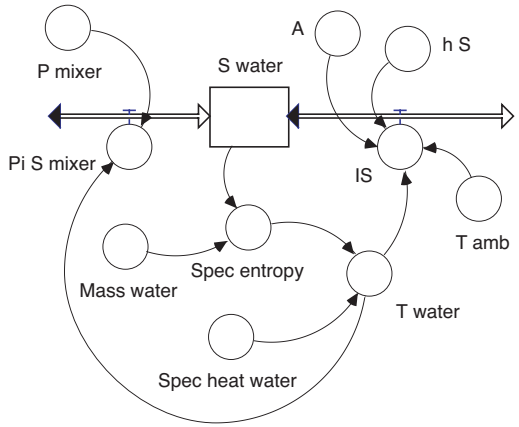
Sadi Carnot's Ansatz und die Übernahme analoger Strukturen aus Theorien von Fluiden und Elektrizität führen zu einer dynamische Theorie der Wärme (Fuchs, 2010a):

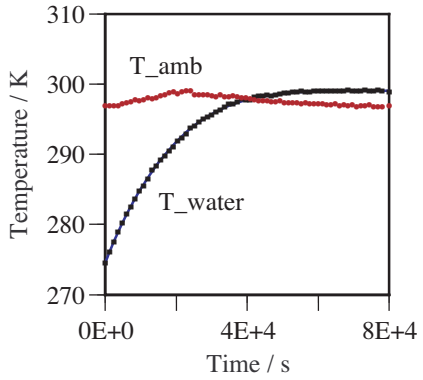
Eigenschaften einer Wärmemenge (Entropie): Speicherung, Transport und Produktion, Bilanz der Entropie

Temperatur als das thermische Niveau (Potential) und Temperaturdifferenz als thermischer Antrieb

Die Kraft der Wärme (Entropie) in Analogie zur Leistung eines Wasserfalls

HEATING COLD WATER IN A WARM ROOM (DOH, CHAPTER 4.6)





Law of balance of entropy:

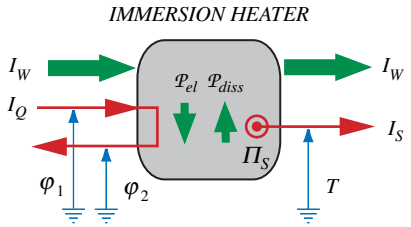
$$\frac{dS_w}{dt} = I_S + \Pi_S$$

Constitutive relations:

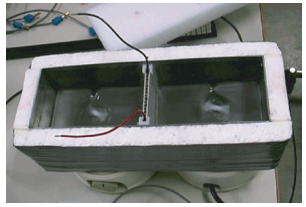
$$T = T_{ref} \exp\left(s/c\right)$$

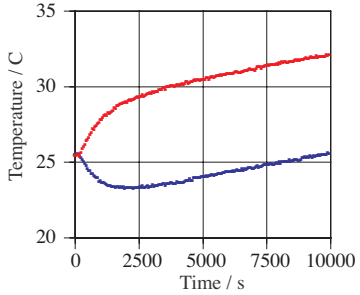
$$I_S = -A h_S \left(T - T_a\right)$$

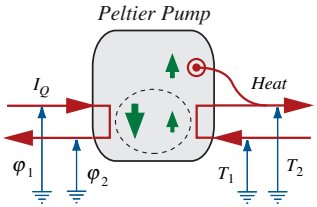
$$\Pi_S = \mathcal{P}_{diss}/T$$



PELTIER DEVICE (DOH, CHAPTER 4.7)



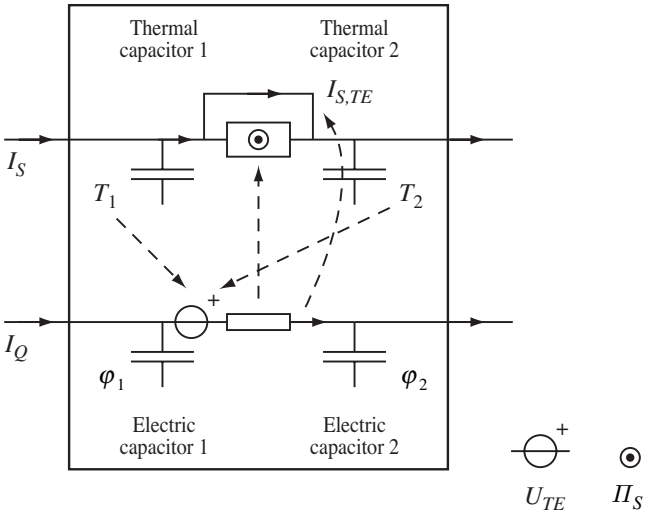


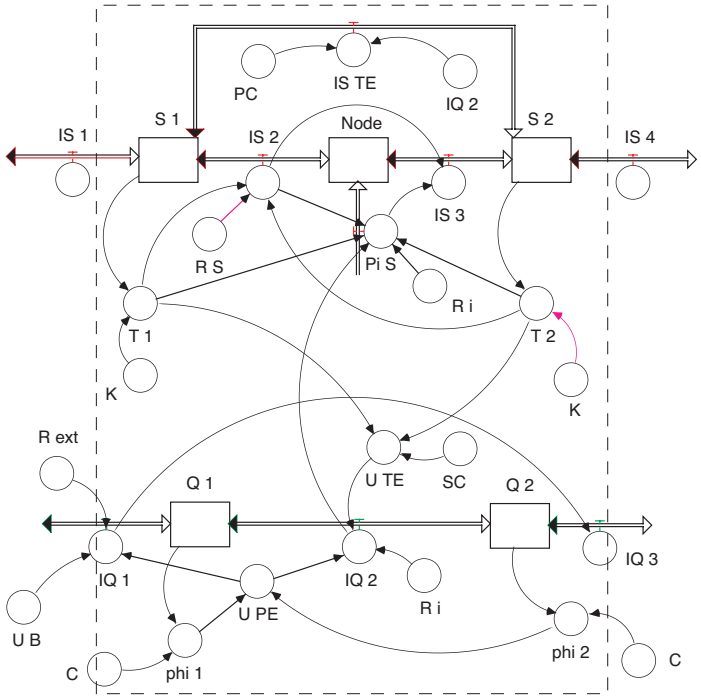


$$I_S = \alpha I_Q - G_S\left(T_2 - T_1\right)$$

$$U = \varepsilon\left(T_2 - T_1\right) + R_i I_Q$$

$$\alpha = \varepsilon$$





THERMODYNAMICS OF A SINGLE VISCOUS FLUID (DOH, CHAPTER 10.1)

ASSUMPTIONS

$$\dot{S} = I_S + \Pi_S$$

$$\dot{E} = I_{E,comp} + I_{E,th}$$

$$P\left(V,T,\dot{V}\right) = P\big|_E\left(V,T\right) + a\dot{V}$$

$$S = S\left(V,T,\dot{V}\right) \quad , \quad E = E\left(V,T,\dot{V}\right) \quad , \quad P = P\left(V,T,\dot{V}\right) \quad , \quad \ldots$$

$$I_{E,th} \propto I_S$$

$$I_{E,comp} = -P\dot{V}$$

CONSEQUENCES

$$I_{E,th} = T\, I_S$$

$$\Pi_S = -\frac{a}{T}\dot{V}^2$$

$$I_S = \Lambda_V \dot{V} + K_V \dot{T} + \frac{a}{T}\dot{V}^2$$

$$\dot{E} = T\,\dot{S} - P\big|_E\,\dot{V}$$

Application of these results to particular examples leads to **initial value problems** (evolution equations for temperature and volume).

Teil 6

FIGURATIVE KONZEPTUALISIERUNGEN IN DER TRADITIONELLEN THERMODYNAMIK UND DER STATISTIK

Welche Schemas und Metaphern, also welche figurativen Strukturen stecken hinter

- der Clausius'schen Thermodynmik
- der kinetischen Theorie
- der statistischen Thermodynamik
- der Informationstheorie?

THERMODYNAMIK UND STATISTIK

Fundamentally, Clausius and Kelvin use the same imaginative figures to conceptualize of thermal processes: quantity of heat, temperature, and power of heat.

The theory of the Force Dynamic Gestalt shows that traditional thermodynamics uses a messed up version of the FDG of thermal processes: **quantity and power of heat are mixed up**.

Naturally, the concept of **quantity of heat** as different from its power comes back to haunt us in the form of **entropy**… (Fuchs, 1986)

Kinetische Theorie …

Statistische Physik …

Informationstheorie …

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