Abstraction in Biomimetics

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What is Abstraction in Biomimetics?

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Outline

1. What is biomimetics?
2. Abstraction in the biomimetic research process
3. Extent definitions of “abstraction”
4. How a biomimetic ontology should model abstraction
5. Conclusion

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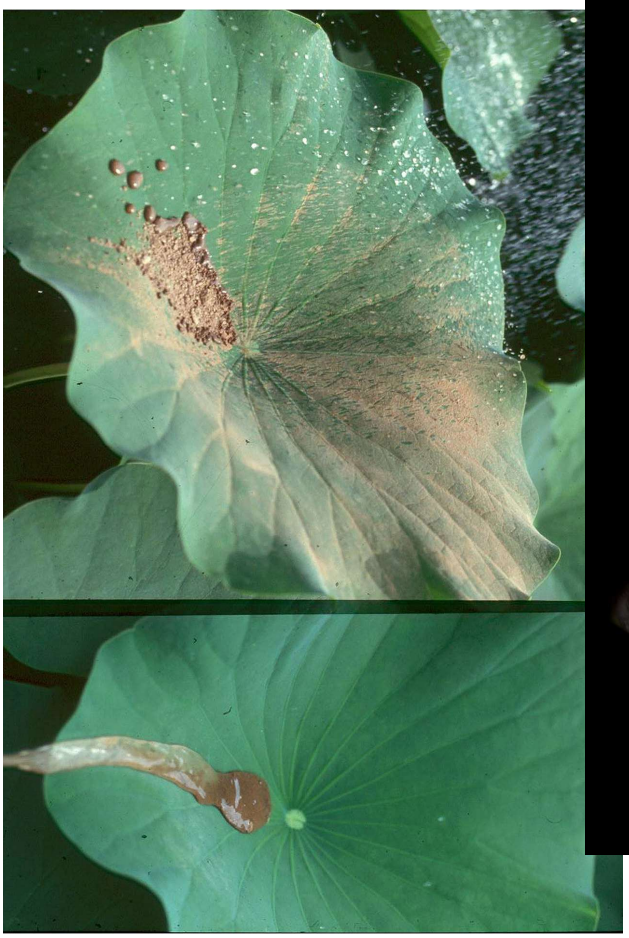

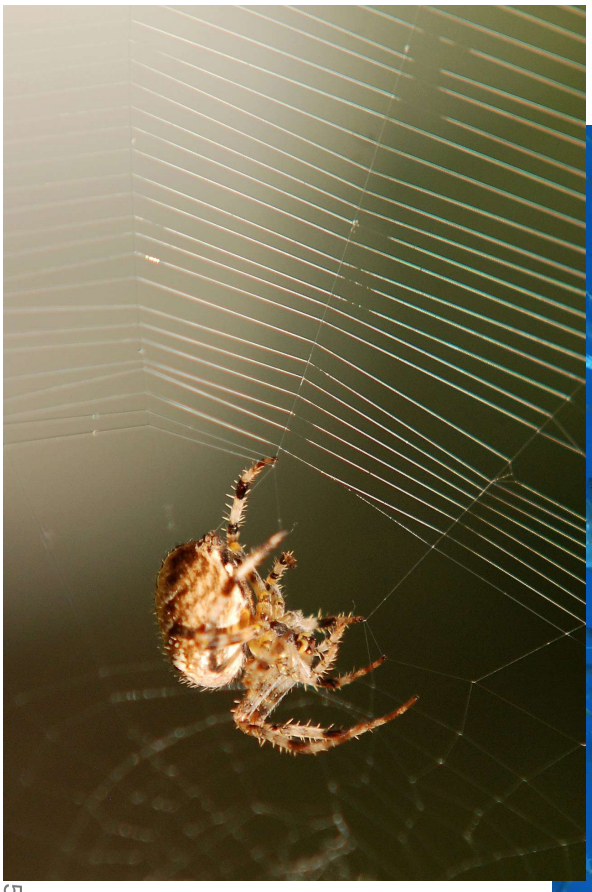

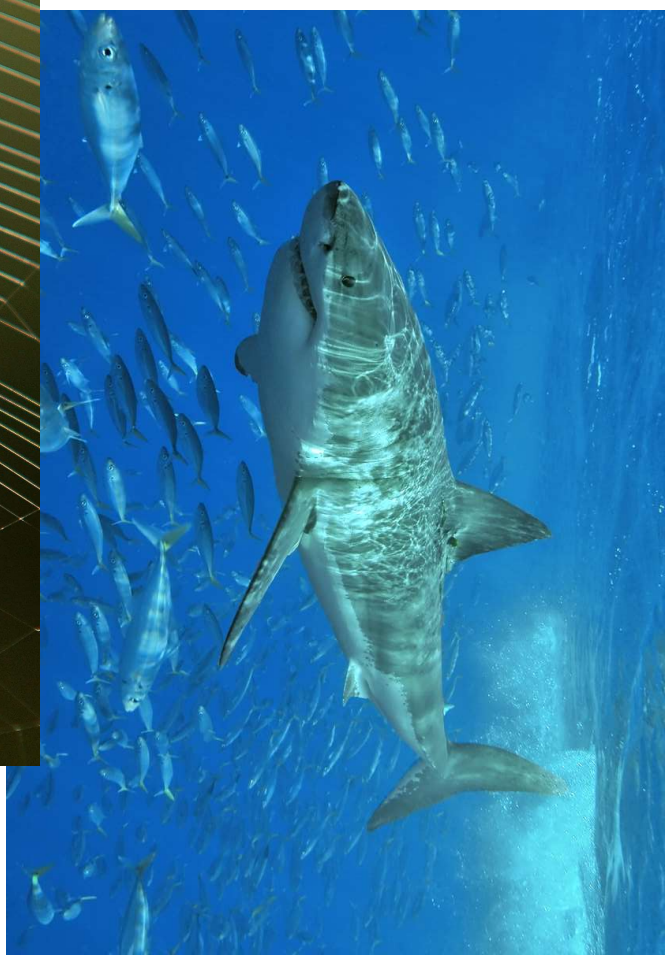

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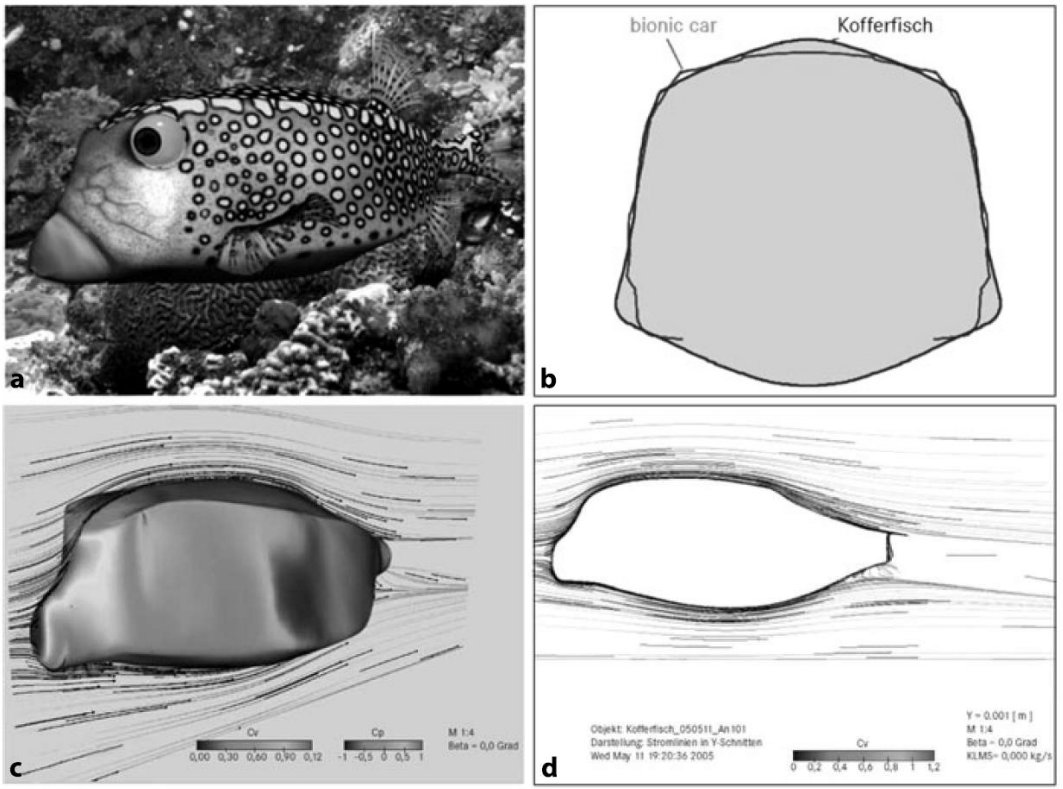

Abb. 6.4 Kofferfisch *Ostracion meleagris* und Mercedes-Benz bionic car. **a** Kofferfisch. **b** Großmodell des bionic car, eingefügt in Kofferfischkonturen. **c**, **d** Strömungssichtbarmachung um Modelle des bionic car. (Abdruckgenehmigung: Daimler AG)

- Nachtigall 2010, 85
- Ryan Somma via Wikimedia

- Nachtigall 2010, 95

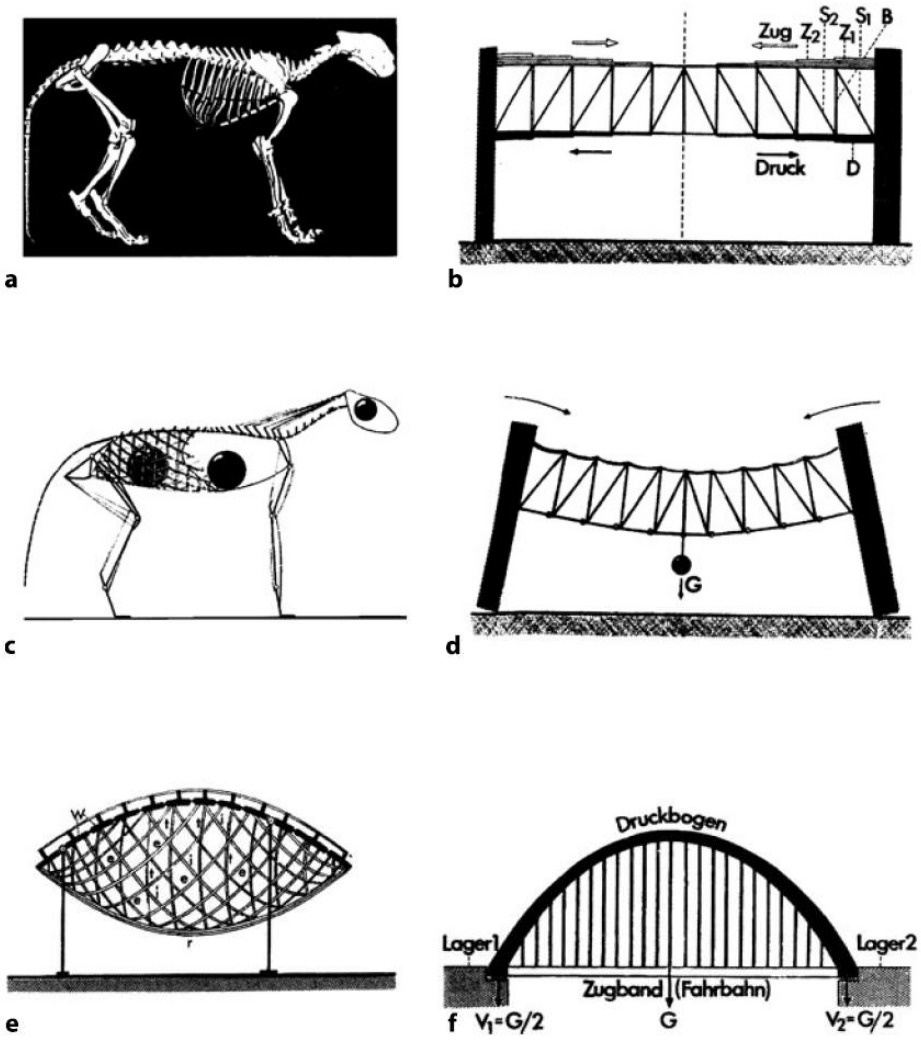

Abb. 6.10 Das Säugerskelett und nicht zutreffende sowie zutreffende Brückenanalogien. **a** Löwenskelett. **b** Nicht zutreffende Kastenbrückenanalogie. **c** Stabil stehendes Säugerskelett. **d** Wenn nicht einfundamentiert, nicht stabile Kastenbrücke. **e** Kippentlastung der Extremitäten durch sich selbst stabilisierendes Rumpfsystem eines Säugers. **f** Zutreffendes Analogon einer Bogen-Sehnen-Brücke. (Kummer 1965)

Why an ontology of biomimetics?

- Biological richness:
  How to find the right biological model from which to learn?
- Interdisciplinary communication:
  How can biologists and engineers find a common language?

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ISO 18458:2015

INTERNATIONAL STANDARD **ISO 18458**

First edition
2015-05-15

Criteria for a biomimetic product			CONCLUSION: Biomimetics yes or no[a]
1. Function analysis of biological system	2. Abstraction from system to model	3. Transfer and application without using the biological system	
+	+	+	yes

Biomimetics — Terminology, concepts and methodology

Biomimétique — Terminologie, concepts et méthodologie

2.9
biomimetics
interdisciplinary cooperation of biology and technology or other fields of innovation with the goal of solving practical problems through the function analysis of *biological systems* (2.6), their *abstraction* (2.1) into *models* (2.15), and the transfer into and application of these models to the solution

Note 1 to entry: Criteria 1 to 3 of Table 1 shall be fulfilled for a product to be biomimetic.

Biomimicry Design Spiral

(https://toolbox.biomimicry.org/methods/process/)

DEFINE
Challenge

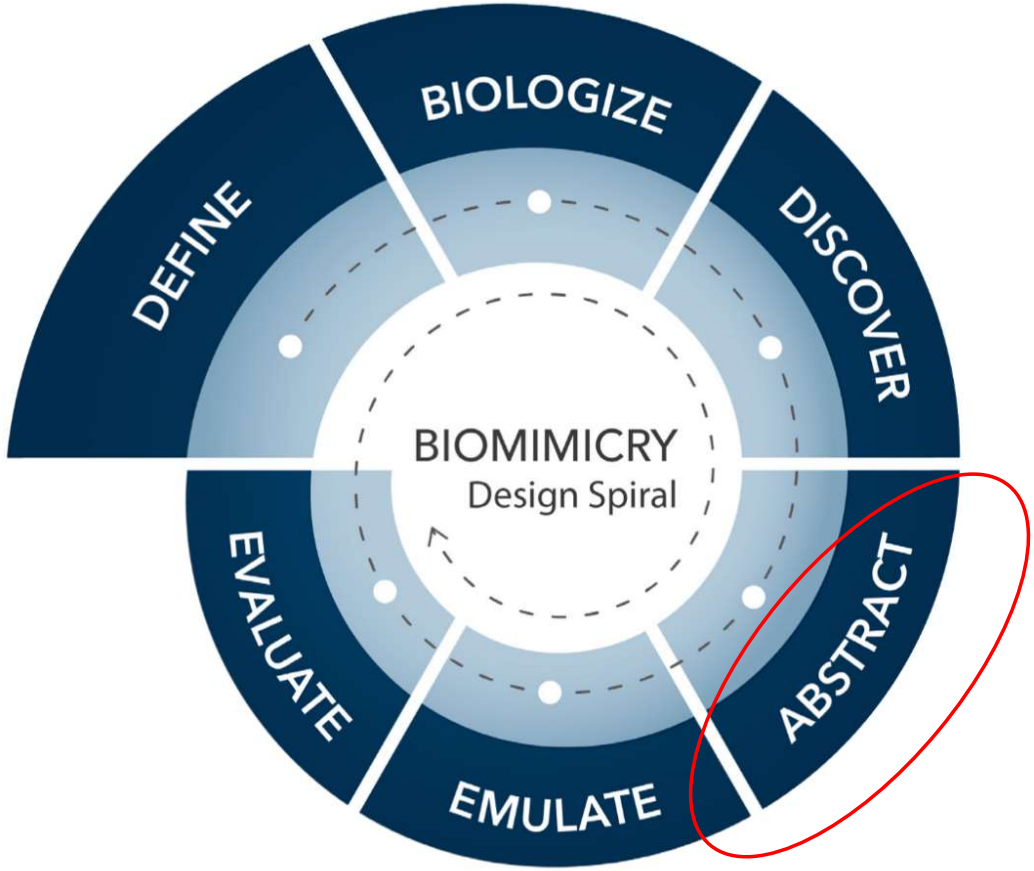
BIOLOGIZE
Function & Context

DISCOVER
Biological Strategies

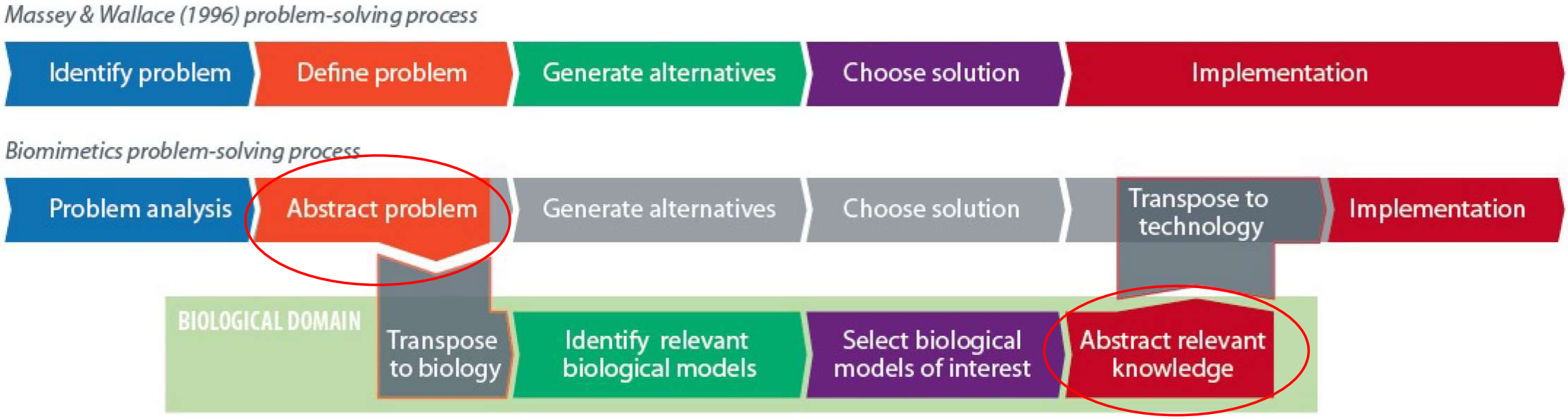
ABSTRACT
Design Strategies

EMULATE
Nature's Lessons

EVALUATE
Fit and Functionality

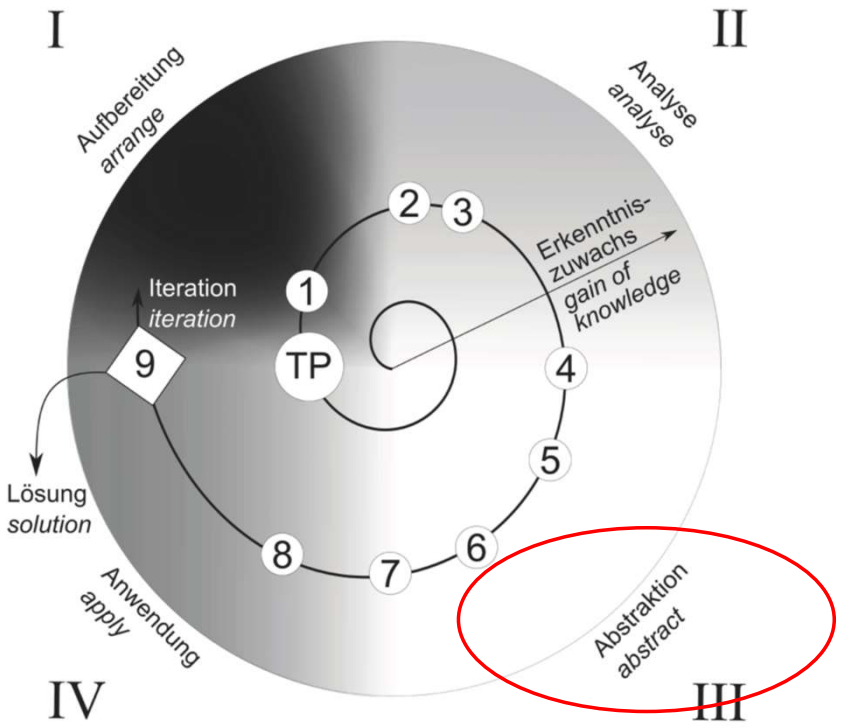


Kruiper et al., Biomimetics 2018, 3(3), 14; https://doi.org/10.3390/biomimetics3030014

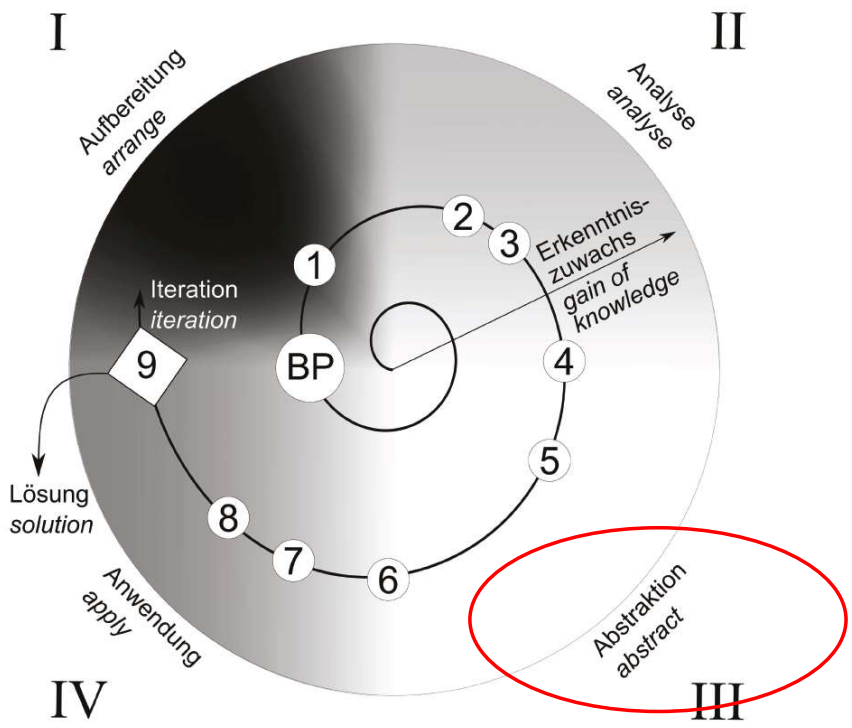


Verein Deutscher Ingenieure
Guideline VDI 6220-2 (2023)

„Technology pull“



„Biology push“



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1. What is biomimetics?
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   c. Source 3: Wanieck, *Biomimetics for Technical Products and Innovation* (2022/2019)
   d. Source 4: Drack et al. 2028
4. How a biomimetic ontology should model abstraction
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Source 1: Guidelines

VDI 6220-2 (2023) on the biomimetic development process

Cites:

VDI 6220-1 (2021) on the conception of biomimetics and its strategies

Same definition as in:

ISO 18458:2015

Both got it from:

VDI 6220-1 (2012)

abstraction

process in which a generalised conclusion is drawn from the observation of a specific object [adapted from VDI 6220 Part 1]

Note 1: This also includes the result of this process.

Note 2: "Abstraction" is also referred to as the mental removal of some features or properties of an object or system that are not relevant to the aspects of its behaviour under investigation.

Note 3: In biomimetics, the result of abstraction is ideally a physical context to describe underlying form-function relationships and operating principles of the biological system. [adapted from VDI 6220 Part 1]

Def.: Is abstraction = generalisation?

- Generalisations standardly called “induction” in logic
- Two variants:
  - This swan is white.
    Hence, all swans are white. Instance → kind
  - Swans can fly.
    Hence, birds can fly. Sub-kind → kind
- Not deductively valid
- Epistemic risk,
- Only probabilistic in nature
- None of these is appropriately called an abstraction

Note 1: Process vs. product

- Process-product ambiguity typical for abstract nouns
- Semantically and ontologically related, but distinct
- Abstraction = a process that leads to a product, i.e., a model
- Model = a “coherent and usable abstraction originating from observations of biological systems” (VDI 6220-1 (2021))

- Problem:
  Inductive inference yields conclusions, i.e., propositions.

Note 2: Abstraction as disregarding detail

Note 2: "Abstraction" is also referred to as the mental removal of some features or properties of an object or system that are not relevant to the aspects of its behaviour under investigation.

Matching definitions from other fields

- Oxford English Dictionary (out of a list of seven possible meanings):
  “The action of considering something in the abstract, independently of its associations or attributes; the process of isolating properties or characteristics common to a number of diverse objects, events, etc., without reference to the peculiar properties of particular examples or instances.” (OED 1987).
- Philosophy of science: “The removal, in thought, of some characteristics or features or properties of an object or a system that are not relevant to the aspects of its behaviour under study.” (Psillos 2007)
- Engineering: “Ignoring what is particular or incidental and emphasizing what is general and essential.” (Pahl et al. 2007)
- Architecture: “Omission or severe simplification of details in drawings of a building or landscape leaving essentials of massing, form, and solids, so that the basis of a design can be explained.” (Curl 1999)

Note 3: „Physical context“?

VDI 6220-1 (2012), ISO 18458:2015:

> “In biomimetics, this conclusion is ideally a physical context for describing the underlying functional and operating principles of the biological model.”

VDI 6220-1 (2021), VDI 6220-2 (2023):

> “In biomimetics, this conclusion is ideally a physical context for describing the underlying form–function relationships and operating principles of the biological system.”

Same category mistake in both formulations:

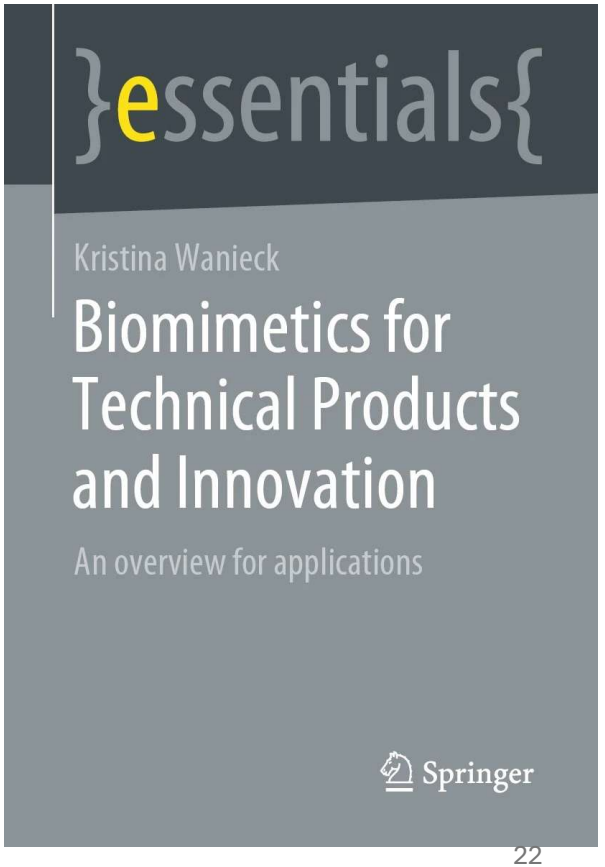
- conclusions of inference steps are propositions
- may be *about* physical contexts but *not identical* to them

Source 2: Werner Nachtigall (2010)

- “abstraction of general principles from ‘original data from biology’”
- “Prinzipabstraktion”:
  - “abstracted principles of nature”
  - real elements of nature to be discovered by the biologists, to be explained in theoretical terms and then to be transferred to engineering
- “Modellabstraktion”: construction of a model
  - “prinzipienabstrahierendes Modell”
  - “modellhafte Prinzipabstraktion”

Source 3: Kristina Wanieck (2022)

Level/Abstractel aspect		Example	Biological model
Level 1	Form – Function	Velcro fastener	Burdocks
Level 2	Physico-chemical principle	Lotus effect	Lotus leaves
Level 3	Innovative principle	Structuring of surfaces	Lotus leaves



Wanieck (2022)

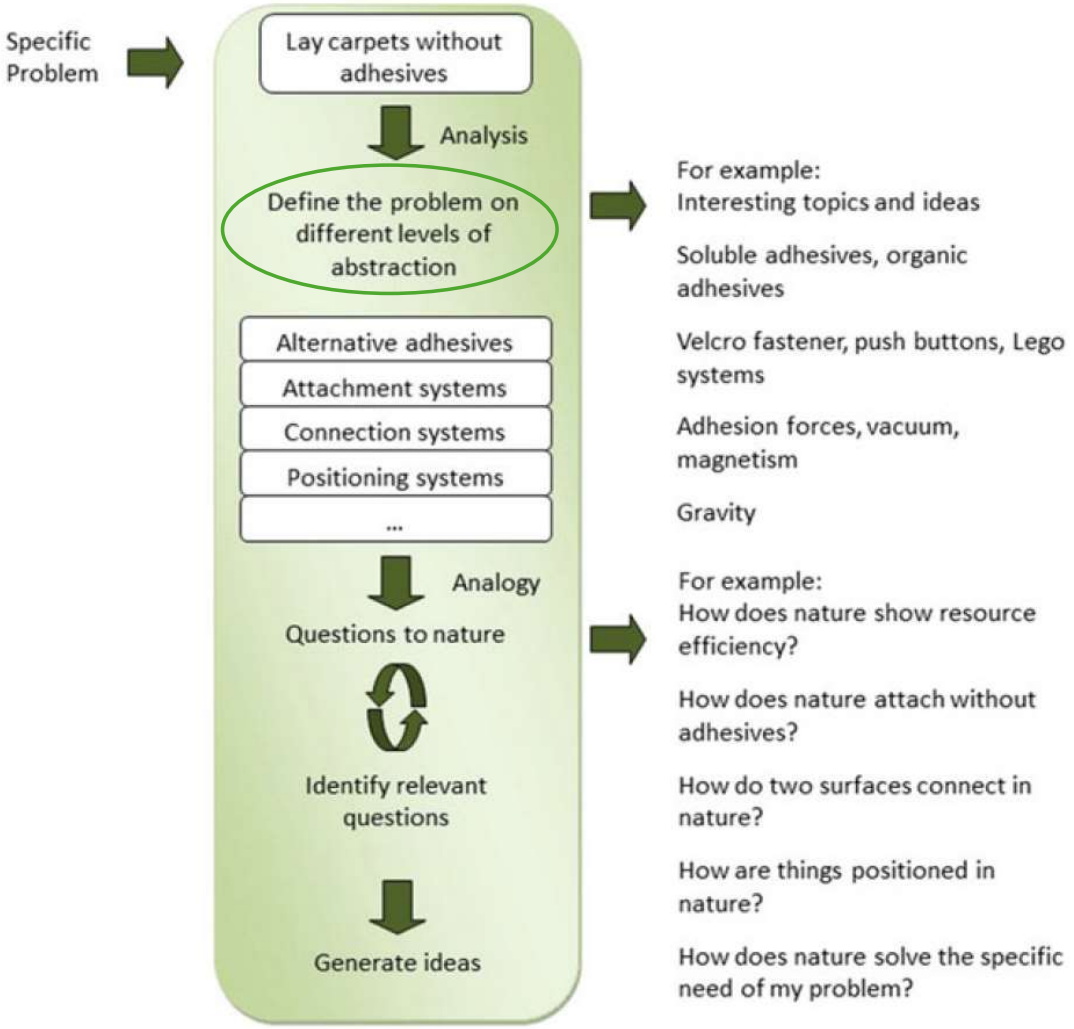


Fig. 3.3 Level of abstraction and different search functions in a sample project

➢ **Sample:** Summary of the biomimetic process for problem solving

Step 1: Problem analysis
- Functional decomposition
- Actual/target situation
- Define target function

Step 2: Problem abstraction
- Determination of the level of abstraction
- Solution-neutral problem description

Step 3: Transfer to biology
- Formulating questions to nature
- Using the language of biology

Step 4: Search for biological models
- Use of search engines and databases
- Consideration of boundary conditions, multifunctionality and solution families

Step 5: Selection of suitable models
- Description of structures and functions
- Comparison of biology and technology

Step 6: Abstraction of biology
- Description of physico-chemical principle
- Functional modelling
- Biological system is not part of the solution

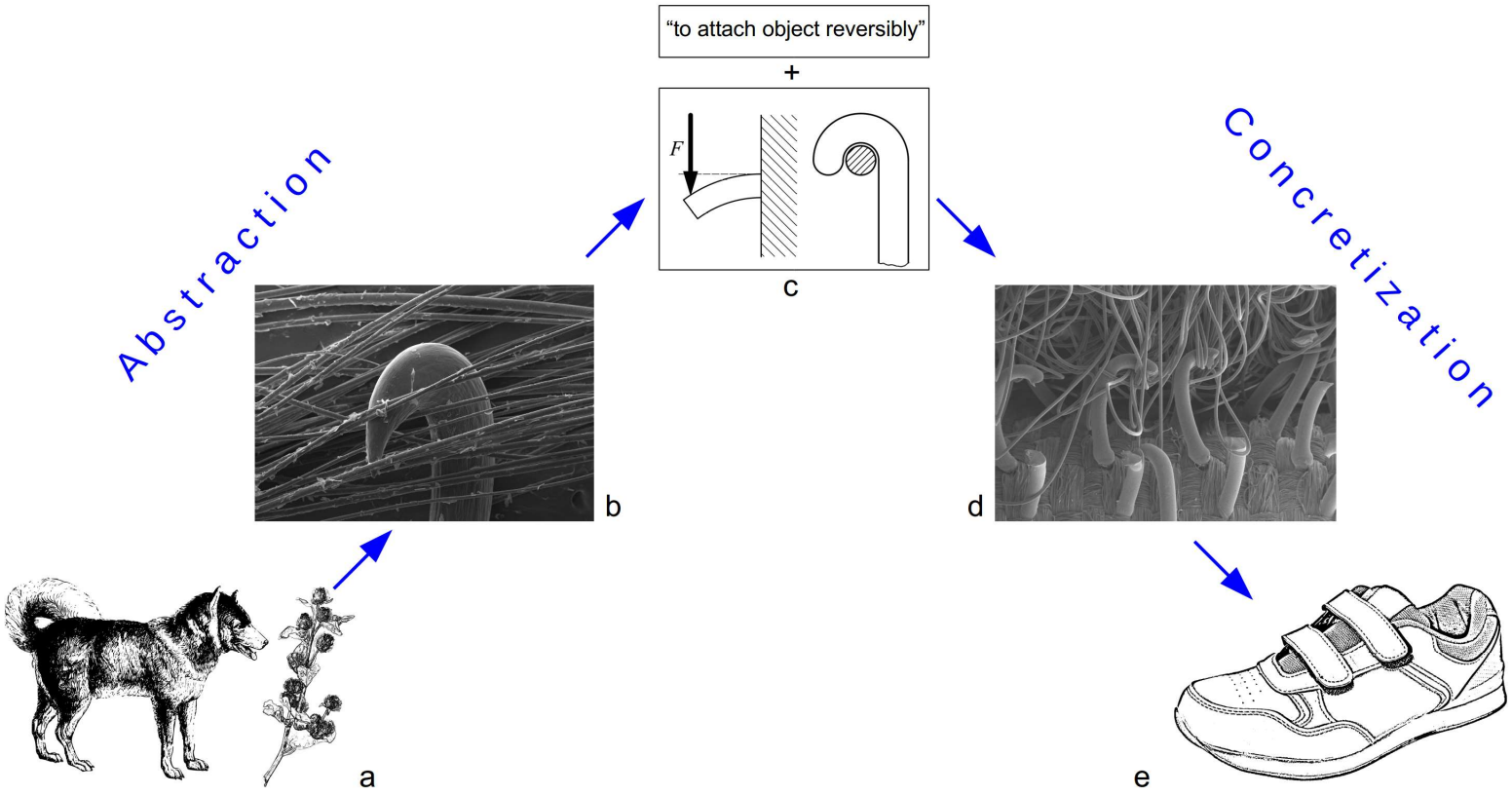
Step 7: Transfer to technology
- Transferability
- Feasibility
- Practicability

Step 8: Application & Tests
- Production
- Market launch
- Sustainability

Fig. 3.4 Summary of the step-by-step application of biomimetics

Source 4: Drack et al. 2018

Ebene
Aufgabe
Funktion
Wirkprinzip
Konstruktion
Übergeordnetes System



Drack et al. 2018

- “The overarching system and the construction in the biological model show many features that are typically not transferred. For instance, the material or the particular shape of the bur [...] are not used in Velcro®. Rather, they are abstracted.” (p. 5)
- “As research progresses, more and more features that are found to be irrelevant for the particular goal are left aside. Correspondingly, the complexity of the investigated item decreases and the degree of abstraction increases [...].” (p. 7)

Abstraction as disregarding detail

- Different stages
  - Phase 1: increasing abstractness in order to abstract functions and working principles from biological model
  - Phase 2: decreasing abstractness in the construction process proper
- Cf. note 3 of VDI 6220-2 (2023): abstraction as disregarding detail
  - “the mental removal of some features or properties of an object or system that are not relevant to the aspects of its behaviour under investigation”

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Where is the consensus?

- Cognitive process

- Starting point in the domain of biology
  - “biological model” = an organism or a certain part of it or a behaviour pattern (or a product of such behaviour) that it displays.
- Result, or product, is a “model”, “principle”, or “function” and “operating principle” or “efficient principle”
- Degrees and/or levels of abstraction

Where is the lack of consensus?

- Cognitive process
  - Sometimes described as a generalization
  - Sometimes as disregarding unnecessary detail.
- Starting point in the domain of biology
  - “biological model” = an organism or a certain part of it or a behaviour pattern (or a product of such behaviour) that it displays.
- Result, or product, is a “model”, “principle”, or “function” and “operating principle” or “efficient principle”
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Discussion: Where is the lack of consensus?

- Cognitive process
  - ~~Sometimes described as a generalization~~
  - Sometimes as disregarding unnecessary detail.
- Starting point in the domain of biology
  - "biological model" = an organism or a certain part of it or a behaviour pattern (or a product of such behaviour) that it displays.
- Result, or product, is a "model", "principle", or "function" and "operating principle" or "efficient principle" (but not a proposition)
- Degrees and/or levels of abstraction

Disregarding vs. focus

- Disregarding unimportant aspects
- Focus on important aspects

The abstract–concrete continuum

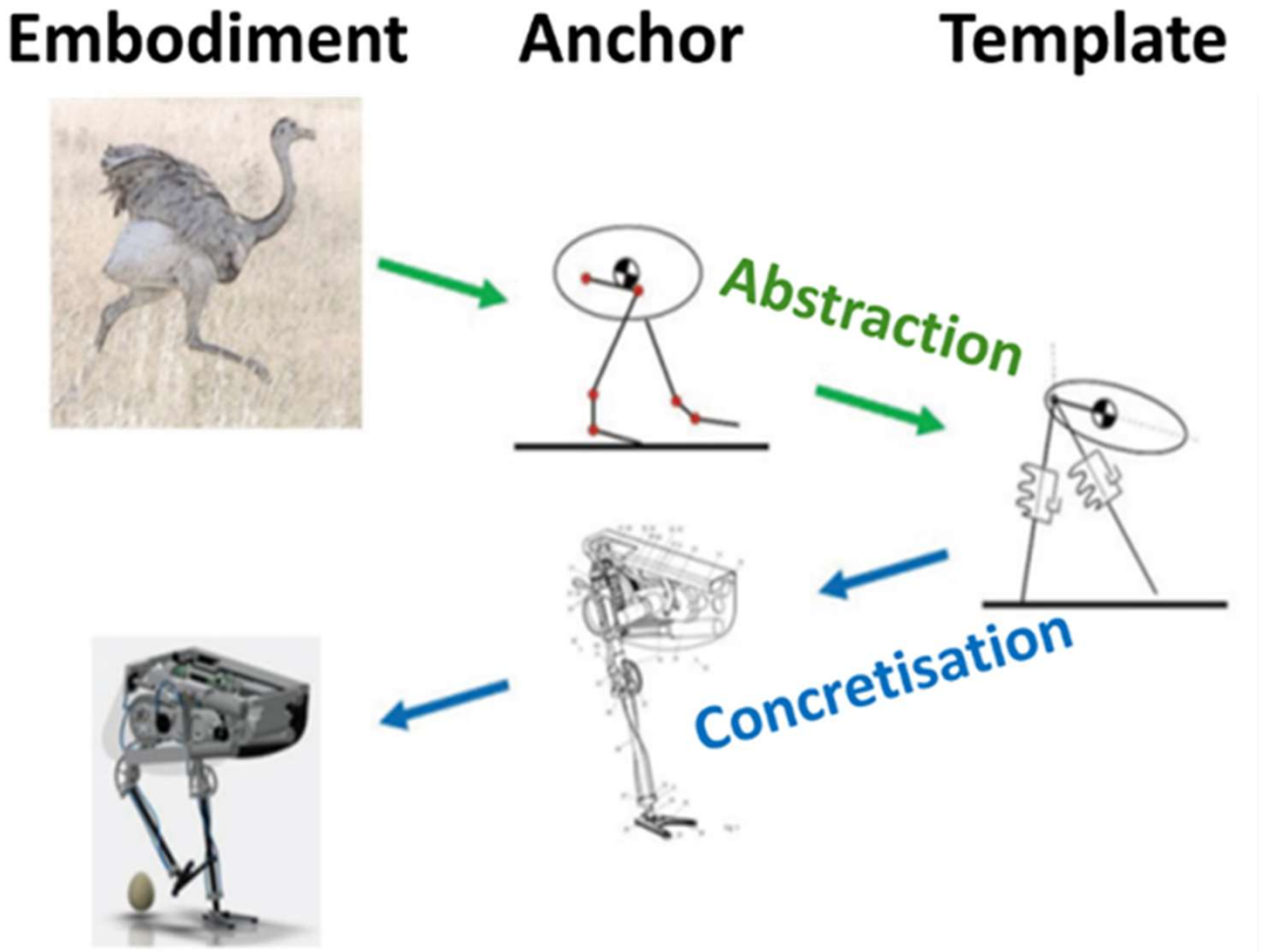
Starting point	Disregarding finitely many aspects	Focus on finitely many aspects
Something not finitely describable (a concrete entity)	Result still not finitely describable	Finitely describable (an abstract entity)
Something finitely describable (an abstract entity)	Something describable in a shorter description	Something describable in a shorter description

Dimensions of abstraction?

- Specificity: going up the species–genus hierarchy
- Granularity: going up the mereological hierarchy of granular partitions (Bittner and Smith 2003).
- Variabilisation: going up the determinate–determinable hierarchy
- Entirely disregarding certain properties: If an entity can be correctly described as having all of a set of properties $\mathbb{P}$, it can also be correctly described as having any subset of $\mathbb{P}$.
- Means–ends hierarchies or causal structures.
- Constitution hierarchies.

Loss of information?

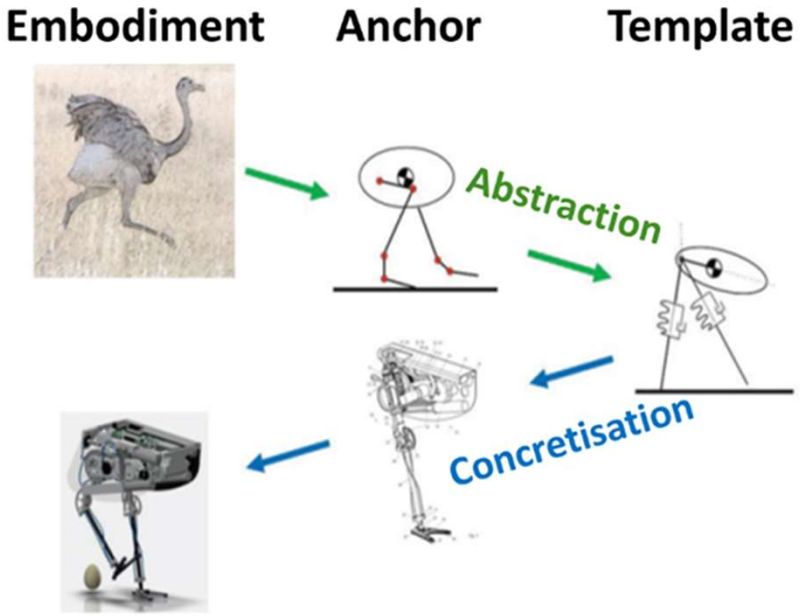
- Not necessarily a bad thing.
- Making models cognitively accessible
  - Cf. maps
- Picking the level of explanatory relevance
  - Why has this figure a sum of inner angles of 180°?
  - Not because it is a polygon (too wide, many other sums).
  - Not because it is an isosceles (too narrow, many other cases).
  - Because it is a triangle!



Development process of the walking robot eNandu. Modified from VDI 6220-2 (2023), p. 23; some drawings taken from the patent specification DE102018103892B4.

Why the generalisation mis-interpretation?

- Abstraction leads to less-detailed models
- Less-detailed models potentially model more cases
  - E.g., several species
  - Organisms *and* machines



Stachowiak 1973. *Allgemeine Modelltheorie*

- „Abstraktion ist, da sie immer auch schrittweise die Begriffsumfänge erweitert, gleichzeitig eine »*generalisierende Abstraktion*«. Letztere ist deutbar als ein »Variabilisieren« von Konstanten.“
- „Z.B. beim Übergang vom Begriff des rechtwinkelig-gleichschenkeligen Dreiecks zu dessen Oberbegriff des gleichschenkeligen Dreiecks: Es wird lediglich das konstante Maß des rechten Winkels durch die über das Intervall aller Winkel zwischen 0 und π laufende Variable ersetzt.
- Vgl. auch G. Klaus, 1963, p. 168: »Die Tätigkeit der Abstraktion besteht nicht im Weglassen von Merkmalen, sondern im Variabelmachen von Merkmalen ... «“

(Stachowiak 1973: 130f)

Conclusion

- Abstraction most appropriately seen as
  - Disregarding detail
  - Focus on certain details
- Result is not a general proposition („For all x …“) but, e.g., a model
- Abstract–concrete continuum
  - Explains degrees of abstraction
  - More abstract models potentially model more cases
- “Levels” rather kinds of objects abstracted
- Dimensions of abstraction: different ontological hierarchies

Thank you! Questions?

Learning from Nature:
Epistemological and Ontological Foundations of Biomimetics
(DFG grant no. 492191929).

https://biomimetics.hypotheses.org

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