Institut für Evolutionsbiologie
und Morphologie

Properties of life

–

Proposal for an integrative concept

Prof. Dr. Bernd Rosslenbroich



Sandregenpfeifer (istockphoto – EstuaryPig)

MICROBIOLOGY AND MOLECULAR BIOLOGY REVIEWS, June 2004, p. 173–186 Vol. 68, No. 2
1092-2172/04/$08.00+0 DOI: 10.1128/MMBR.68.2.173–186.2004
Copyright © 2004, American Society for Microbiology. All Rights Reserved.

A New Biology for a New Century

Carl R. Woese*

Department of Microbiology, University of Illinois, Urbana, Illinois 61801

INTRODUCTION 173
THE MOLECULAR ERA IN THE BIGGER PICTURE 173
Reductionism versus Reductionism 174
Synthesis 175
TOWARDS A NEW REPRESENTATION OF BIOLOGY 175
CHANGING THE OVERVIEW 176
SOME PERTINENT HISTORY 176
THE PANDORA'S BOX OF MICROBIOLOGY 177
The Dismantling of Bacteriology and a Deconstruction of the Procaryote 177
Other Guesswork Solutions? 179
CELLULAR EVOLUTION: THE BUMPY ROAD TO WHO KNOWS WHERE 179
THE DYNAMICS OF CELLULAR EVOLUTION 180
The Key to Understanding the Character of HGT 181
From There to Here 182
An Interesting, if Not Relevant, Aside 183
When Is a Tree Not a Tree? 183
ONE LAST LOOK 184
REFERENCES 185

INTRODUCTION

Science is an endless search for truth. Any representation of reality we develop can be only partial. There is no finality, sometimes no single best representation. There is only deeper understanding, more revealing and enveloping representations. Scientific advance, then, is a succession of newer representations superseding older ones, either because an older one has run its course and is no longer a reliable guide for a field or because the newer one is more powerful, encompassing, and productive than its predecessor(s).

Science is impelled by two main factors, technological advance and a guiding vision (overview). A properly balanced relationship between the two is key to the successful development of a science: without the proper technological advances the road ahead is blocked. Without a guiding vision there is no road ahead; the science becomes an engineering discipline, concerned with temporal practical problems. In its heyday the representation that came to dominate and define 20th century biology, molecular biology, was a rich and inspiring blend of the two. By the end of the 20th century, however, the molecular vision of biology had in essence been realized; what it could see of the master plan of the living world had been seen, leaving only the details to be filled in. How else could one rationalize the strange claim by some of the world's leading molecular biologists (among others) that the human genome (a medically inspired problem) is the "Holy Grail" of biology? What a stunning example of a biology that operates from an engineering perspective, a biology that has no genuine guiding vision!

* Mailing address: Department of Microbiology, University of Illinois, 601 S. Goodwin, Urbana, IL 61801. Phone: (217) 333-9369. Fax: (217) 244-6697. E-mail: carl@ninja.life.uiuc.edu.

Look back a hundred years. Didn't a similar sense of a science coming to completion pervade physics at the 19th century's end—the big problems were all solved; from here on out it was just a matter of working out the details? Deja vu! Biology today is no more fully understood in principle than physics was a century or so ago. In both cases the guiding vision has (or had) reached its end, and in both, a new, deeper, more invigorating representation of reality is (or was) called for.

A society that permits biology to become an engineering discipline, that allows that science to slip into the role of changing the living world without trying to understand it, is a danger to itself. Modern society knows that it desperately needs to learn how to live in harmony with the biosphere. Today more than ever we are in need of a science of biology that helps us to do this, shows the way. An engineering biology might still show us how to get there; it just doesn't know where "there" is.

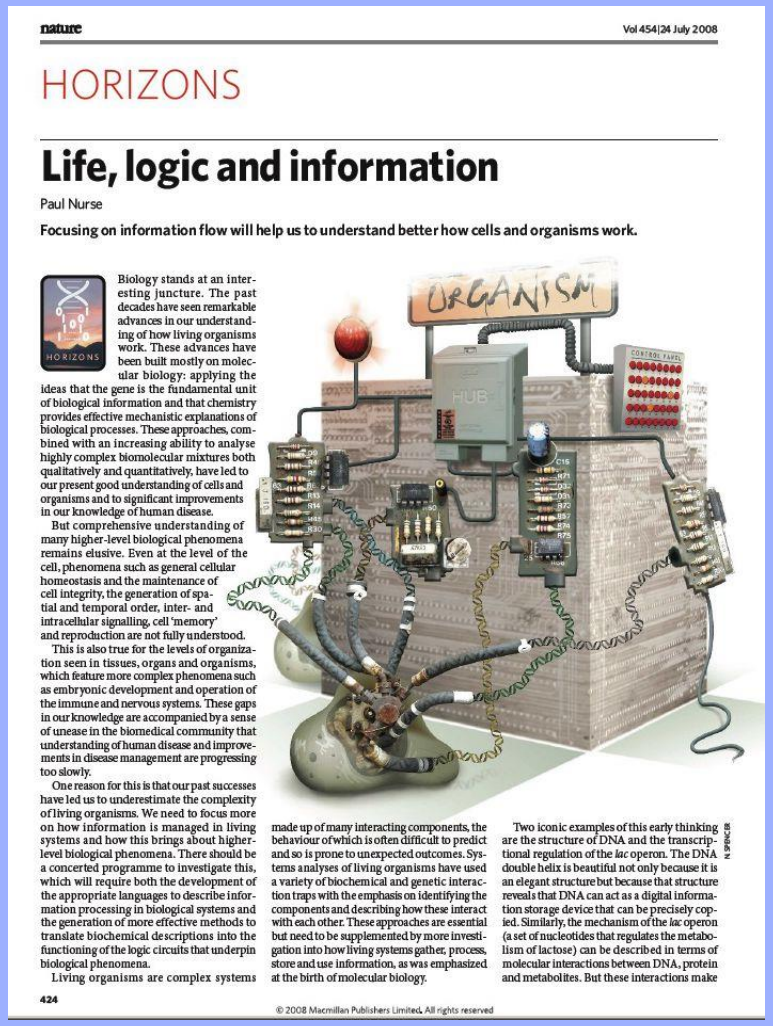
THE MOLECULAR ERA IN THE BIGGER PICTURE

If the dominant molecular representation of biology is to be displaced by something deeper, something more comprehensive and inspiring, we need first to step back, define molecular biology, and place the molecular era into proper historical perspective.

Despite the fact that historians may well declare the 20th to be "the great century" in biology (24), it was in the 19th century that biology really came of age; consolidating itself, ridding itself of much of its ancient burden of mystical claptrap, and defining the great biological problems: Pasteur had banished spontaneous generation for good. He, along with Koch, Haeckel, Cohn, Beijerinck, and others, had shown the living world to comprise far more than plants and animals. Darwin had demystified evolution and recast it scientifically. The cell had

"Let's stop looking at the organism purely as a molecular machine..."

Woese CR (2004): A new biology for a new century. Microbiology and Molecular Biology Reviews 68, 137-186



nature Vol 454|24 July 2008

HORIZONS

Life, logic and information

Paul Nurse

Focusing on information flow will help us to understand better how cells and organisms work.

Biology stands at an interesting juncture. The past decades have seen remarkable advances in our understanding of how living organisms work. These advances have been built mostly on molecular biology: applying the ideas that the gene is the fundamental unit of biological information and that chemistry provides effective mechanistic explanations of biological processes. These approaches, combined with an increasing ability to analyse highly complex biomolecular mixtures both qualitatively and quantitatively, have led to our present good understanding of cells and organisms and to significant improvements in our knowledge of human disease.

But comprehensive understanding of many higher-level biological phenomena remains elusive. Even at the level of the cell, phenomena such as general cellular homeostasis and the maintenance of cell integrity, the generation of spatial and temporal order, inter- and intracellular signalling, cell 'memory' and reproduction are not fully understood.

This is also true for the levels of organization seen in tissues, organs and organisms, which feature more complex phenomena such as embryonic development and operation of the immune and nervous systems. These gaps in our knowledge are accompanied by a sense of unease in the biomedical community that understanding of human disease and improvements in disease management are progressing too slowly.

One reason for this is that our past successes have led us to underestimate the complexity of living organisms. We need to focus more on how information is managed in living systems and how this brings about higher-level biological phenomena. There should be a concerted programme to investigate this, which will require both the development of the appropriate languages to describe information processing in biological systems and the generation of more effective methods to translate biochemical descriptions into the functioning of the logic circuits that underpin biological phenomena.

Living organisms are complex systems made up of many interacting components, the behaviour of which is often difficult to predict and so is prone to unexpected outcomes. Systems analyses of living organisms have used a variety of biochemical and genetic interaction traps with the emphasis on identifying the components and describing how these interact with each other. These approaches are essential but need to be supplemented by more investigation into how living systems gather, process, store and use information, as was emphasized at the birth of molecular biology.

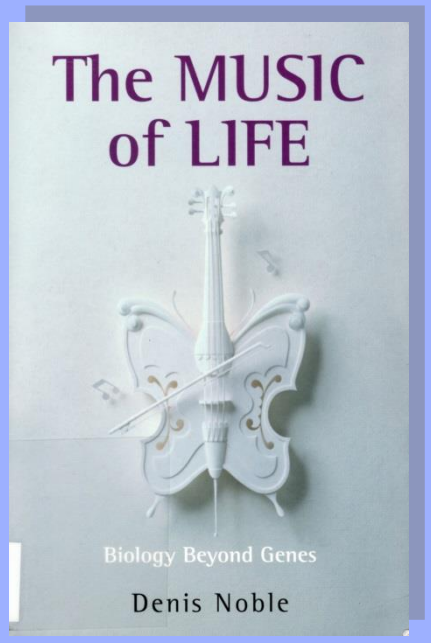
Two iconic examples of this early thinking are the structure of DNA and the transcriptional regulation of the *lac* operon. The DNA double helix is beautiful not only because it is an elegant structure but because that structure reveals that DNA can act as a digital information storage device that can be precisely copied. Similarly, the mechanism of the *lac* operon (a set of nucleotides that regulates the metabolism of lactose) can be described in terms of molecular interactions between DNA, protein and metabolites. But these interactions make

N. SPENCER

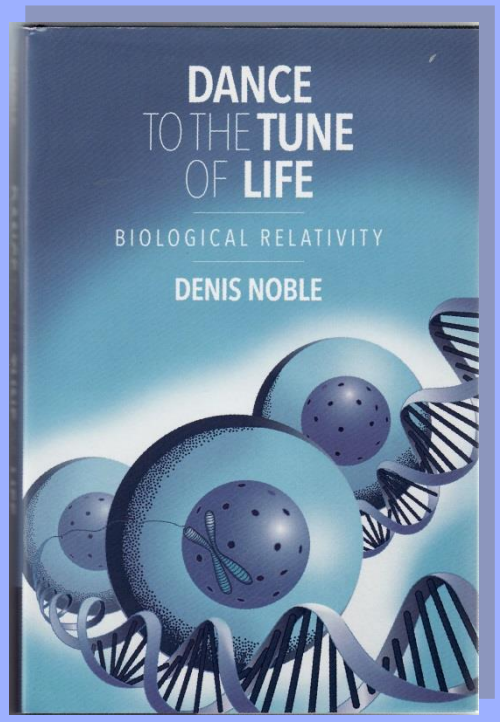
© 2008 Macmillan Publishers Limited. All rights reserved

"Biology stands at an interesting juncture. The past decades have seen remarkable advances in our understanding of how living organisms work. […] But comprehensive understanding of many higher-level biological phenomena remains elusive. ..."

Nurse P (2008): Life, logic and information. Nature 454, 424-426



Noble D (2006): The music of life. Biology beyond genes. Oxford Univ. Press



Noble D (1017): Dance to the Tune of Life. Biological Relativity. Cambridge Univ. Press

„What is life? Noble argues that we must look beyond the reductionist gene‘s view of life to answer the question...“



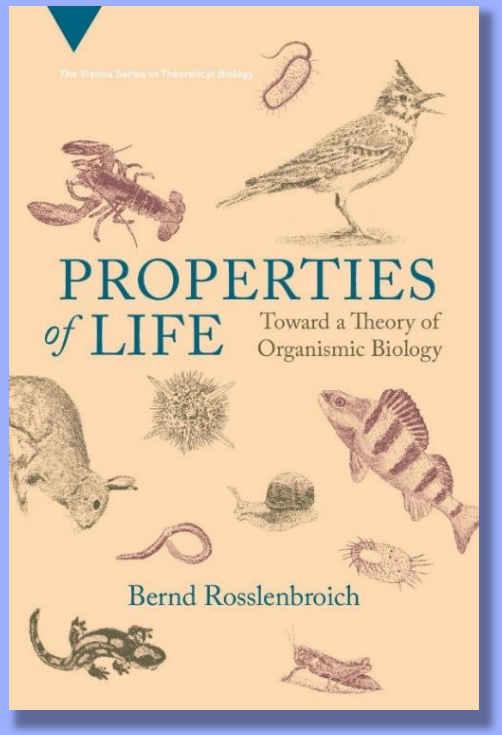
Sandregenpfeifer (iStock – EstuaryPig)

Intentions:

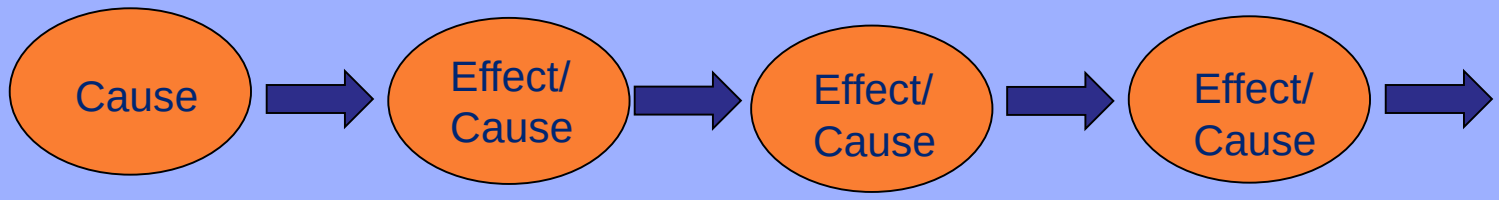
- Concept for organismic biology

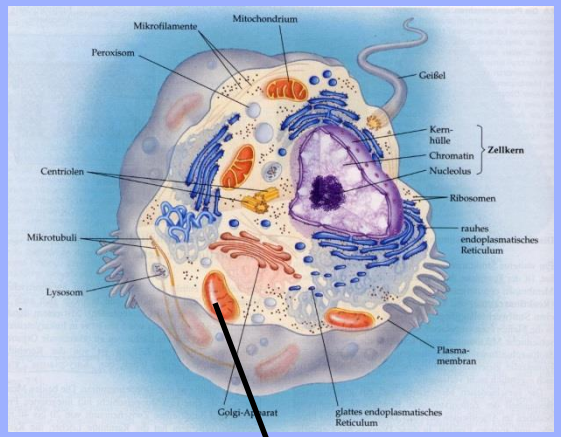
- Ontologically irreducible concept of the living

- Background for dealing with organisms in practice



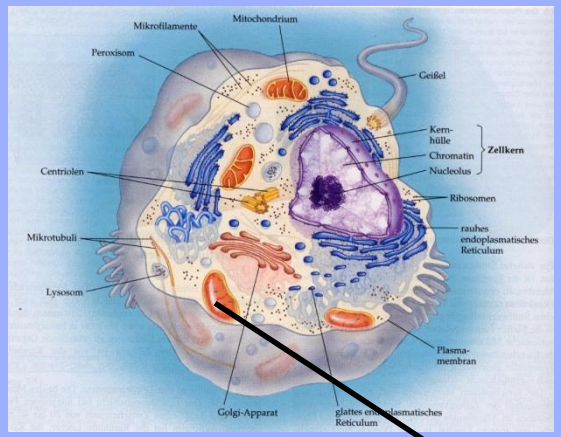
MIT Press 2023

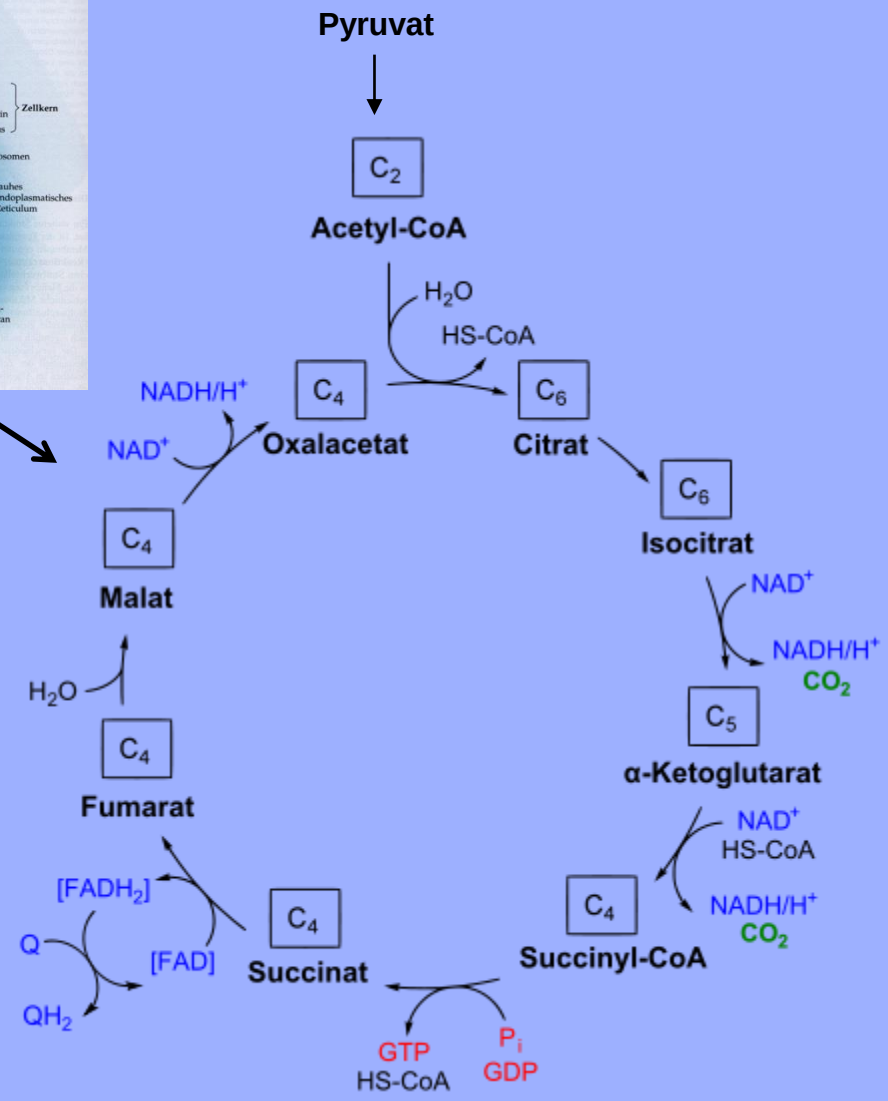

Cause
Effect/
Cause
Effect/
Cause
Effect/
Cause



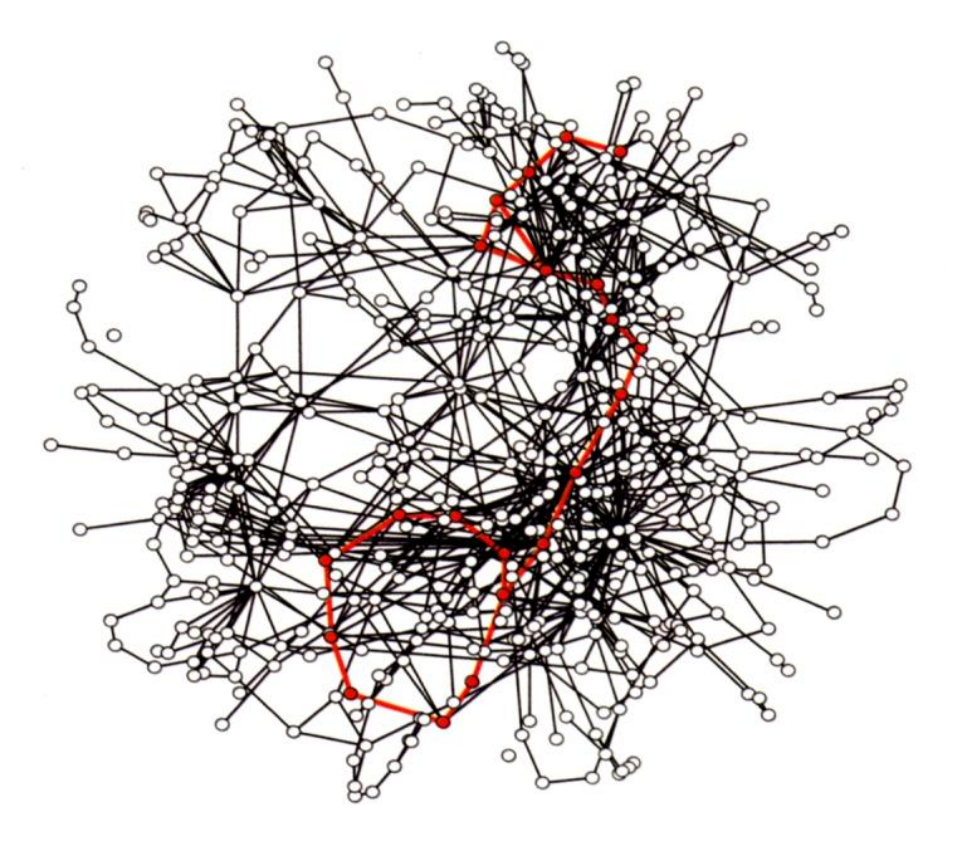
Succinat → Fumarat → Malat → Oxalacetat → Pyruvat → Citrat

Zelle:



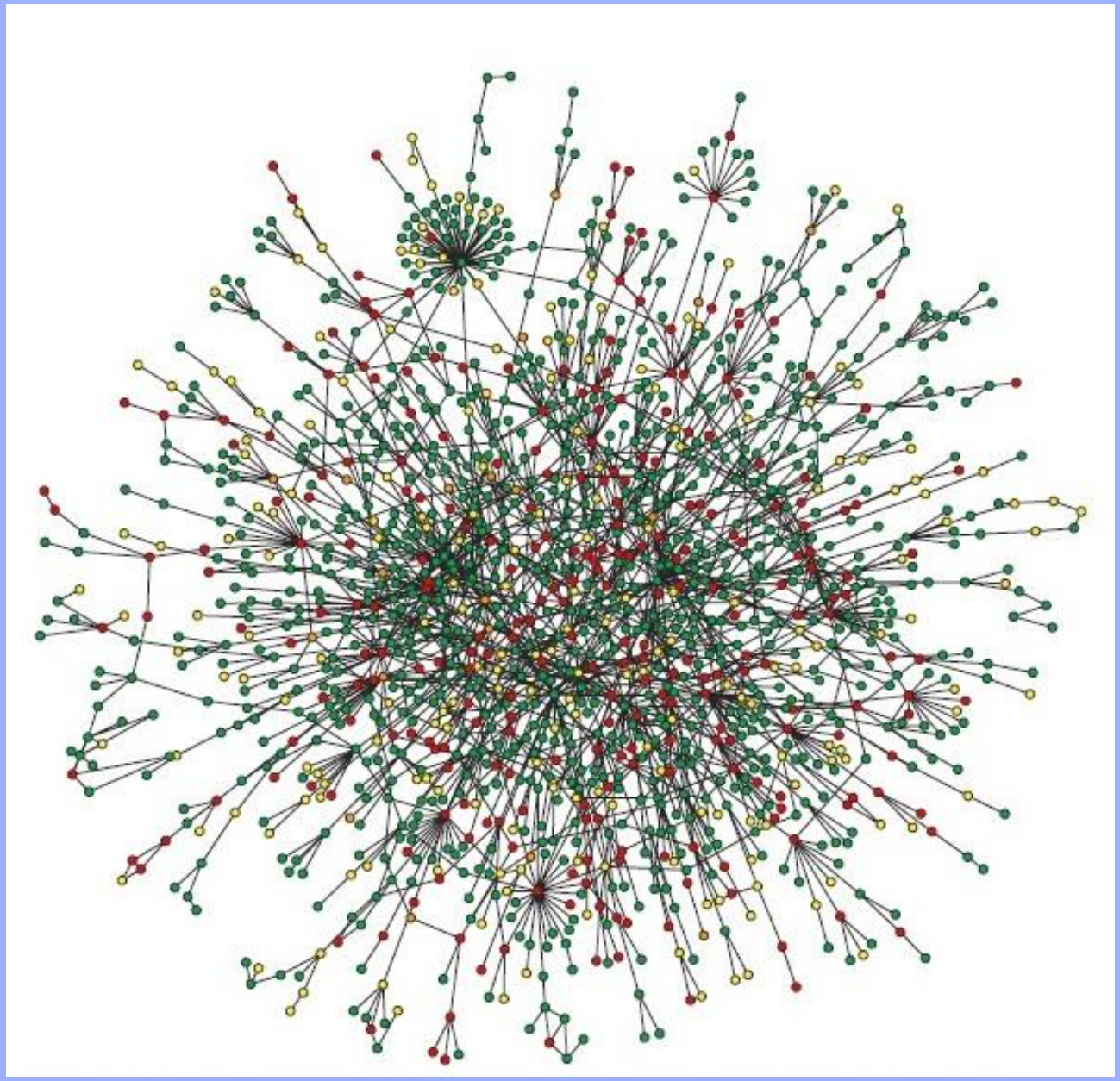


Citric acit cycle



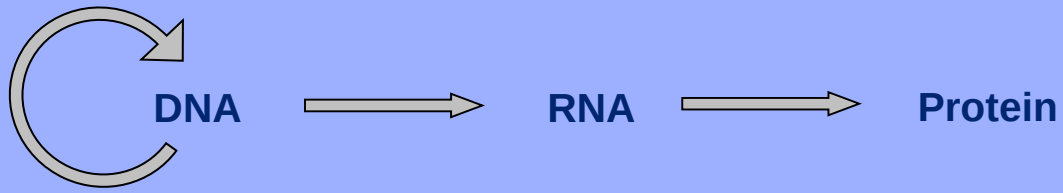
Overview representation of all known metabolic reactions involving small molecules in a yeast cell. Reactions of glycolysis and the citric acid cycle in red.

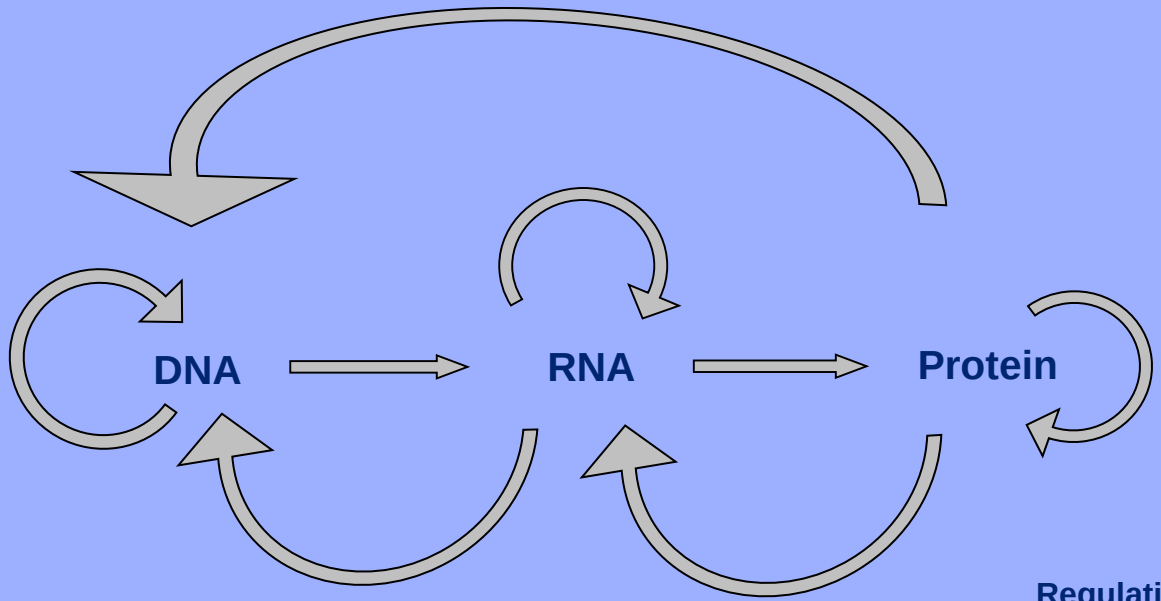
From: Alberts et al: Molekularbiologie der Zelle (2004)



Yeast protein interaction network (*Saccharomyces cerevisiae)*.
The color of a node indicates the phenotypic effect of removing the corresponding protein
red = lethal,
green = non-lethal,
orange = slow growth,
yellow = unknown.
(from Barabási & Oltvai 2004)


DNA
RNA
Protein





Regulation of chromatin structure

Methylation

Transcription factors

Micro RNAs

Splicing

Regulation of translation

RNA editing

Regulation after translation

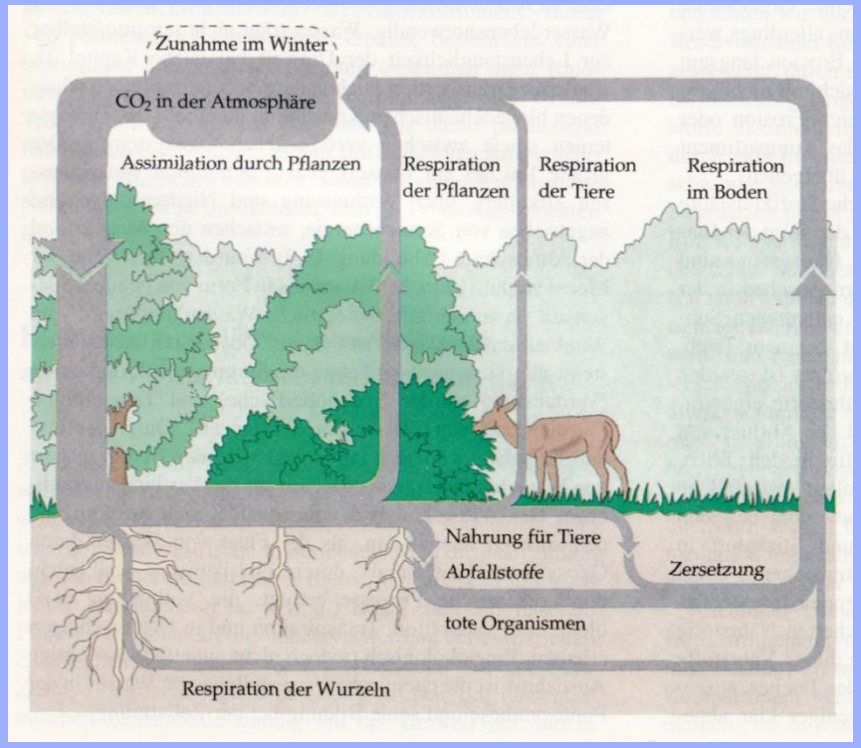
Activation

Selective degradation

Protein folding

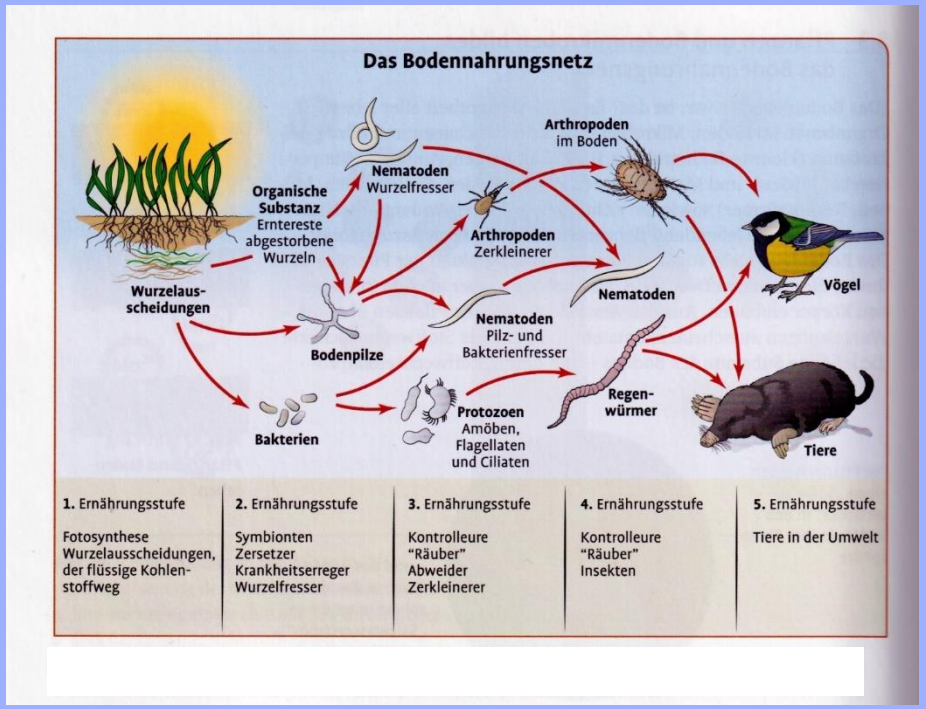
Epigenetics

Illustration:
Johannes Wirz



The carbon cycle

Aus: Campbell NA (1997): Biologie. Spektrum Verlag Heidelberg, Berlin



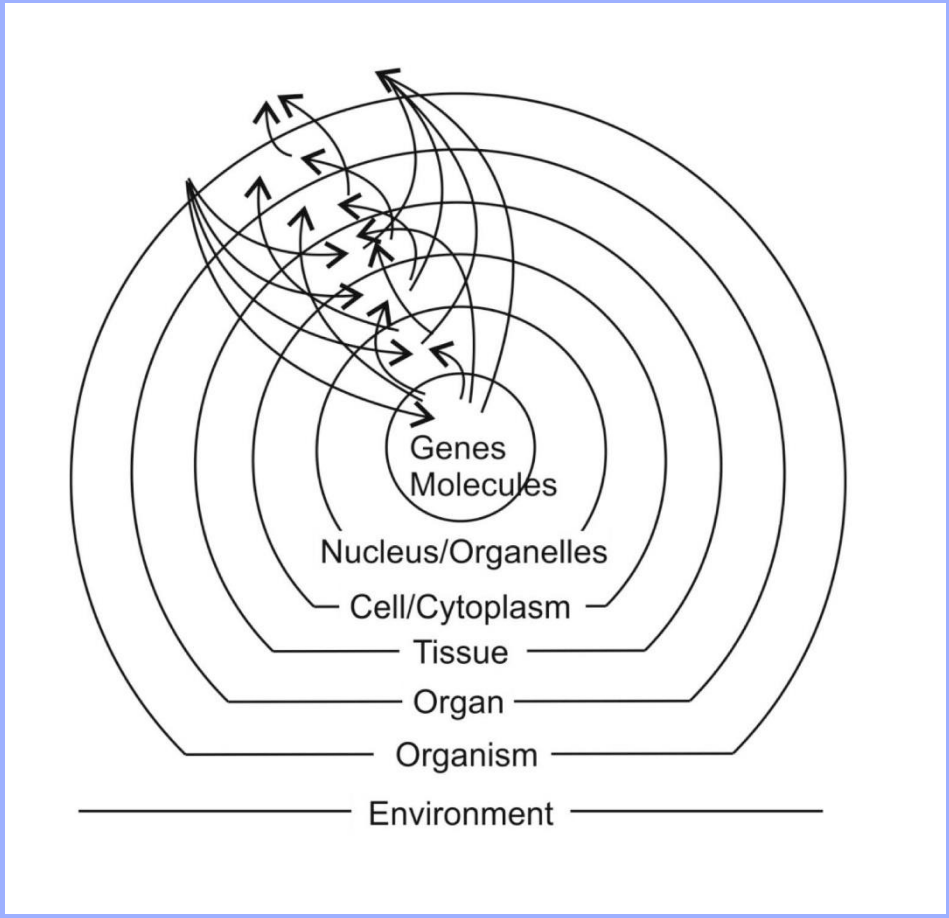
The bottom feeding net

Aus: Näser D (2020): Regenerative Landwirtschaft. Ulmer, Stuttgart

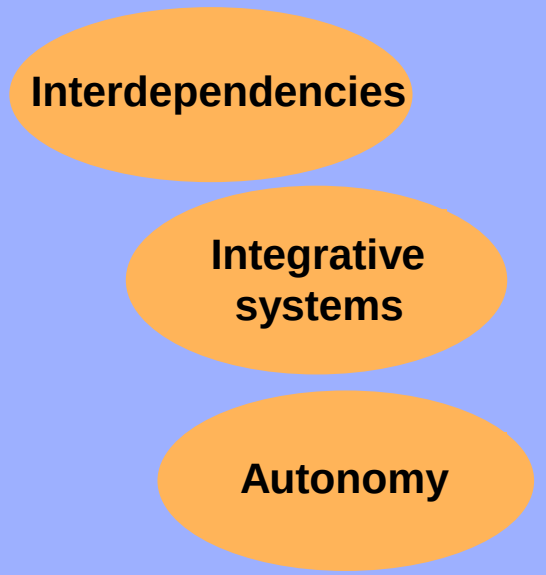
Interdependencies

Interdependencies

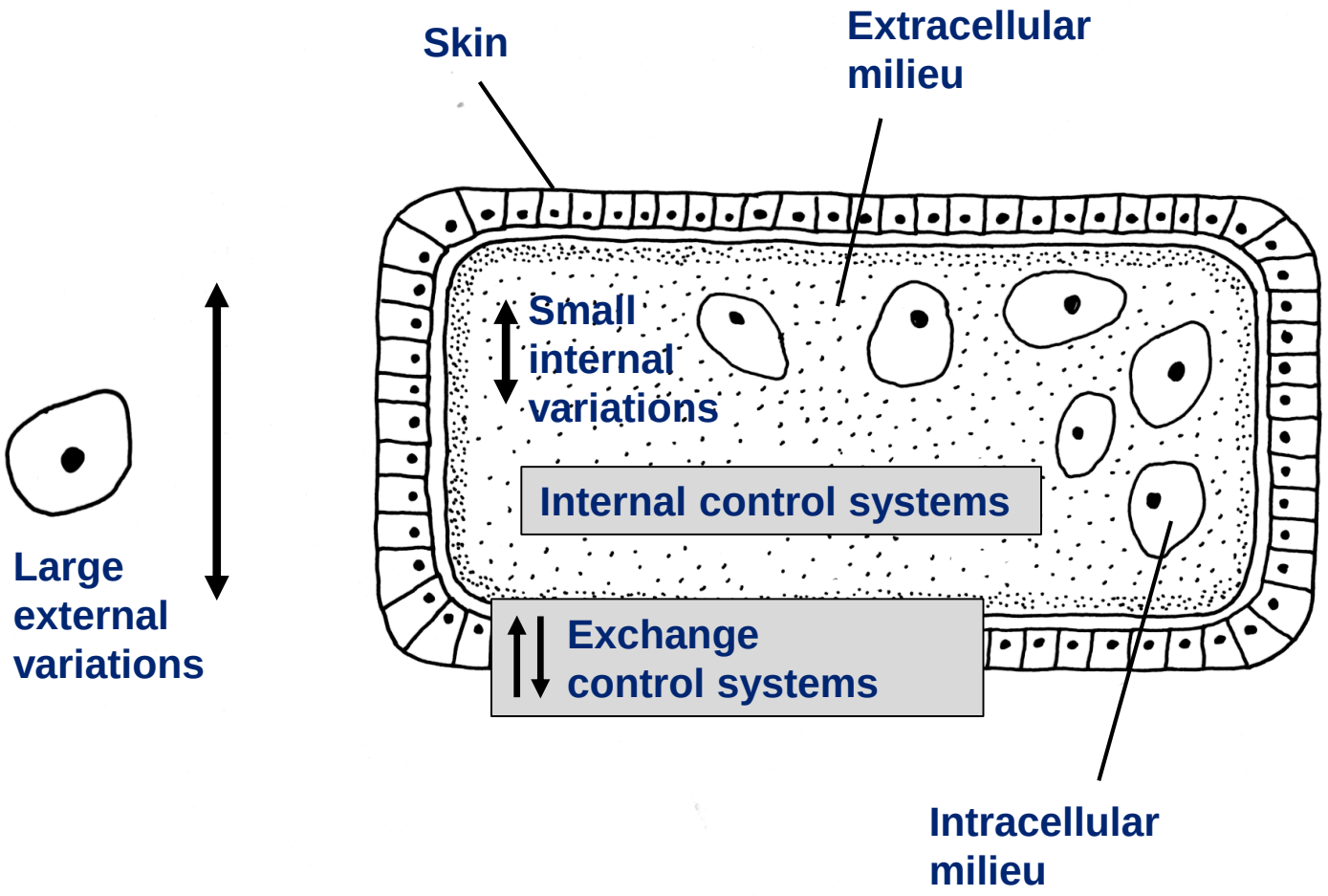
Integrative systems



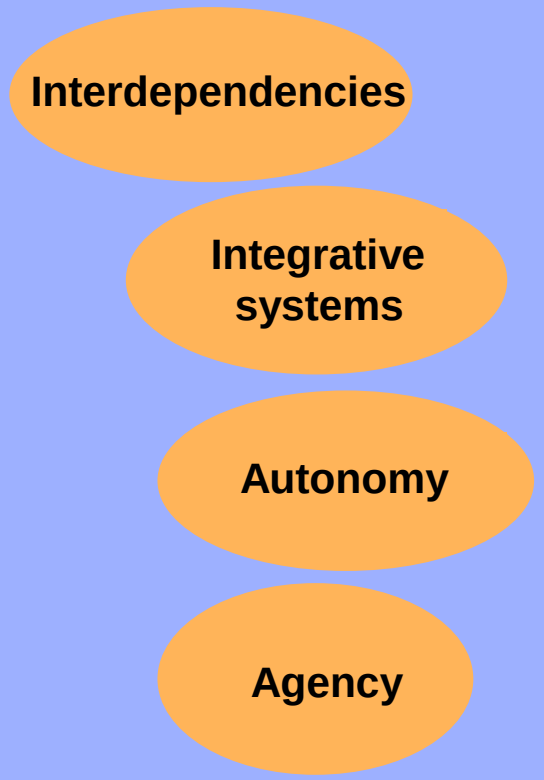
Paul A. Weiss (1969) The living system: determinism stratified. In *Beyond Reductionism. New Perspectives in the Life Sciences.* ed. Koestler A., and Smythies J.R., 3-55. London: Hutchinson.


Interdependencies
Integrative systems
Autonomy

Features of autonomy increase in the emergence of multicellularity

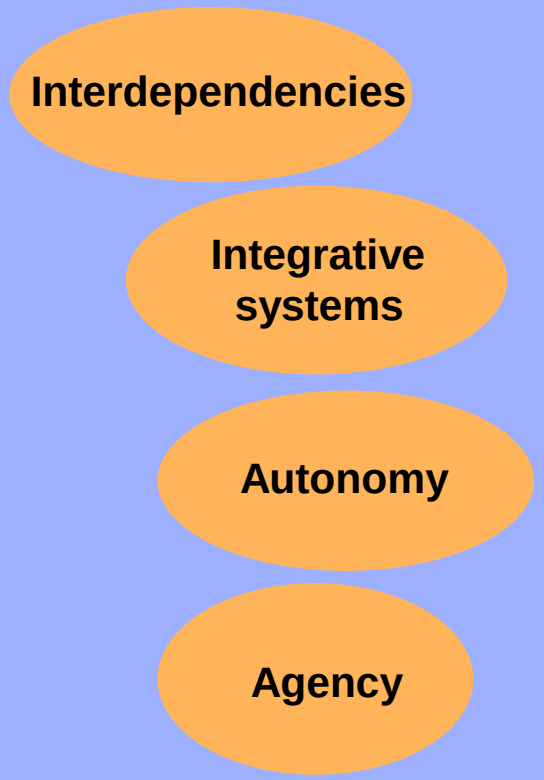


Rosslenbroich B (2014): On the origin of autonomy - a new look at the major transitions in evolution. Springer

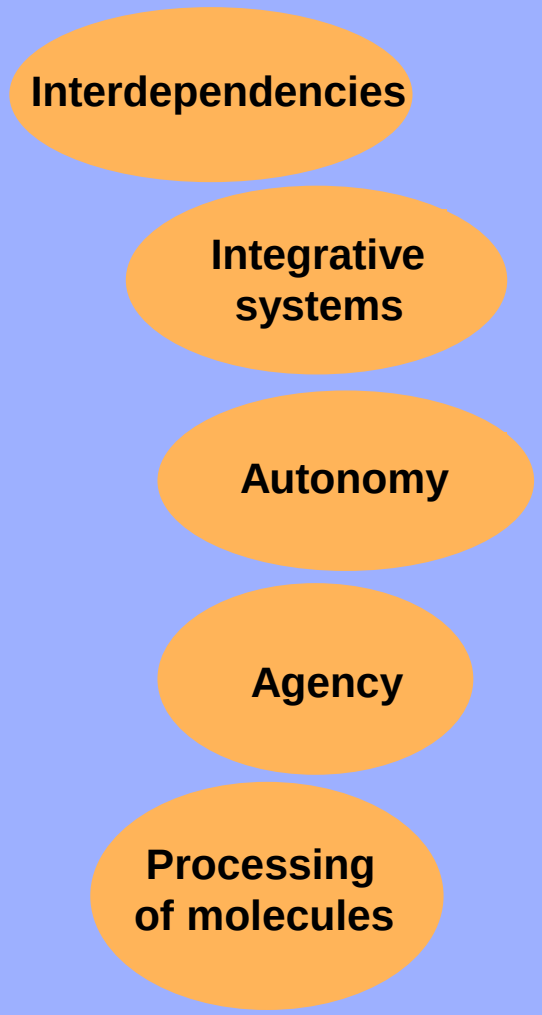

Interdependencies
Integrative systems
Autonomy
Agency

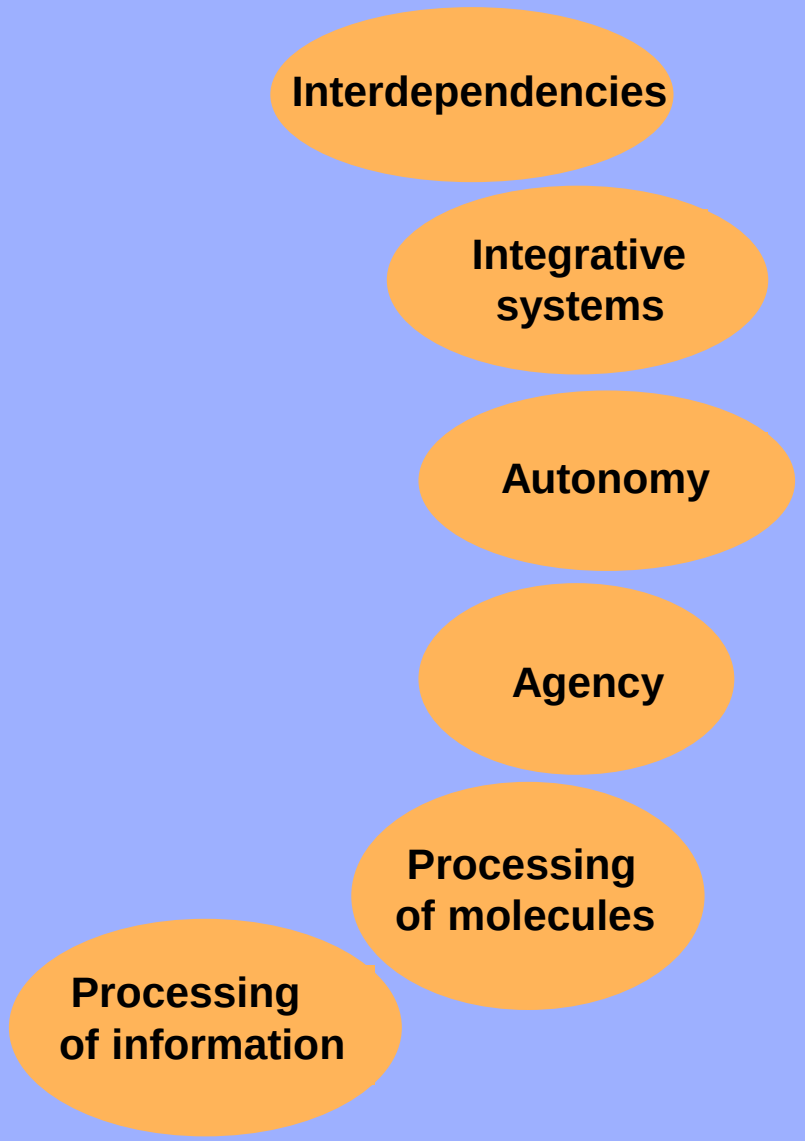


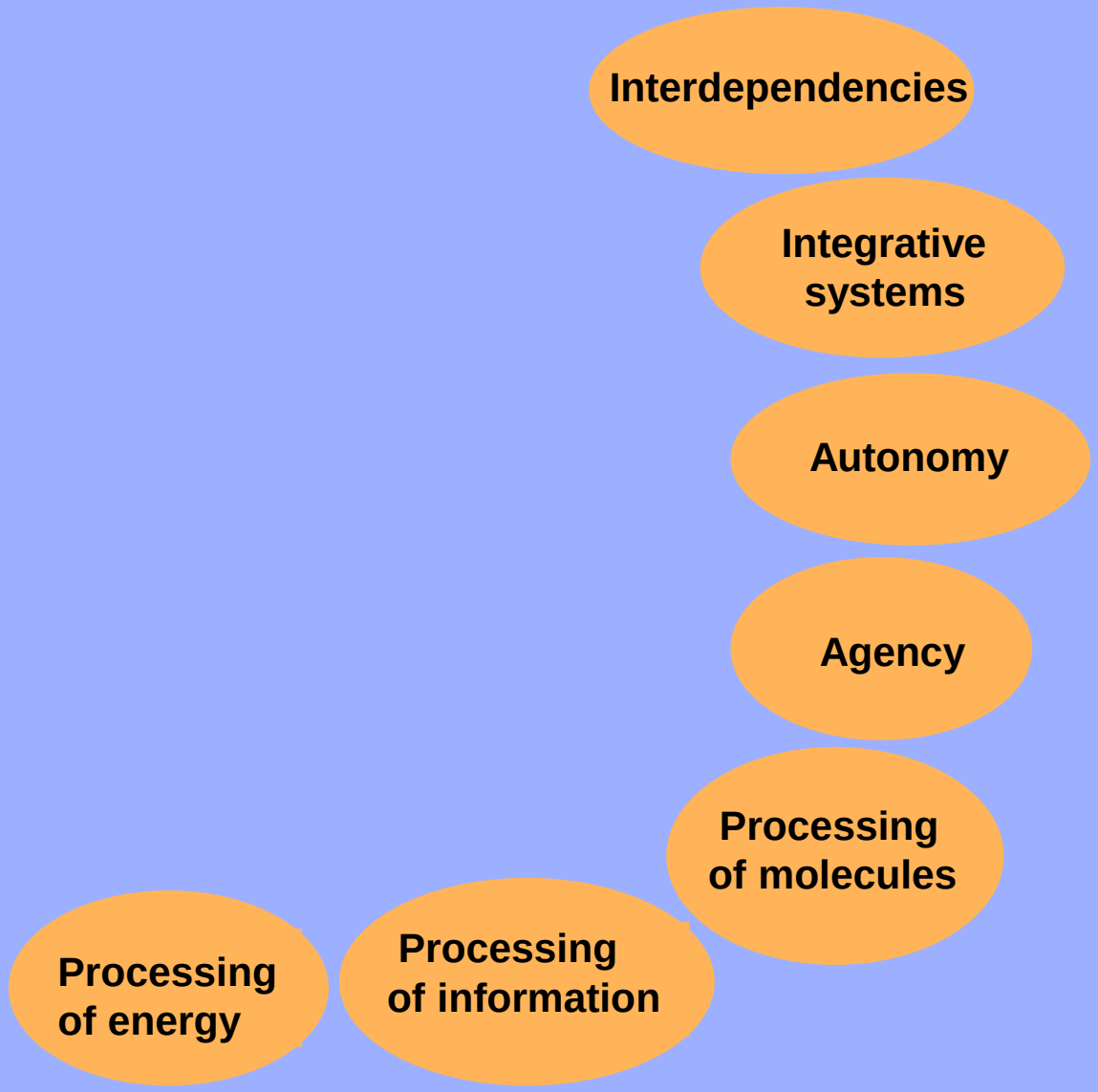
iStock PerfectStills

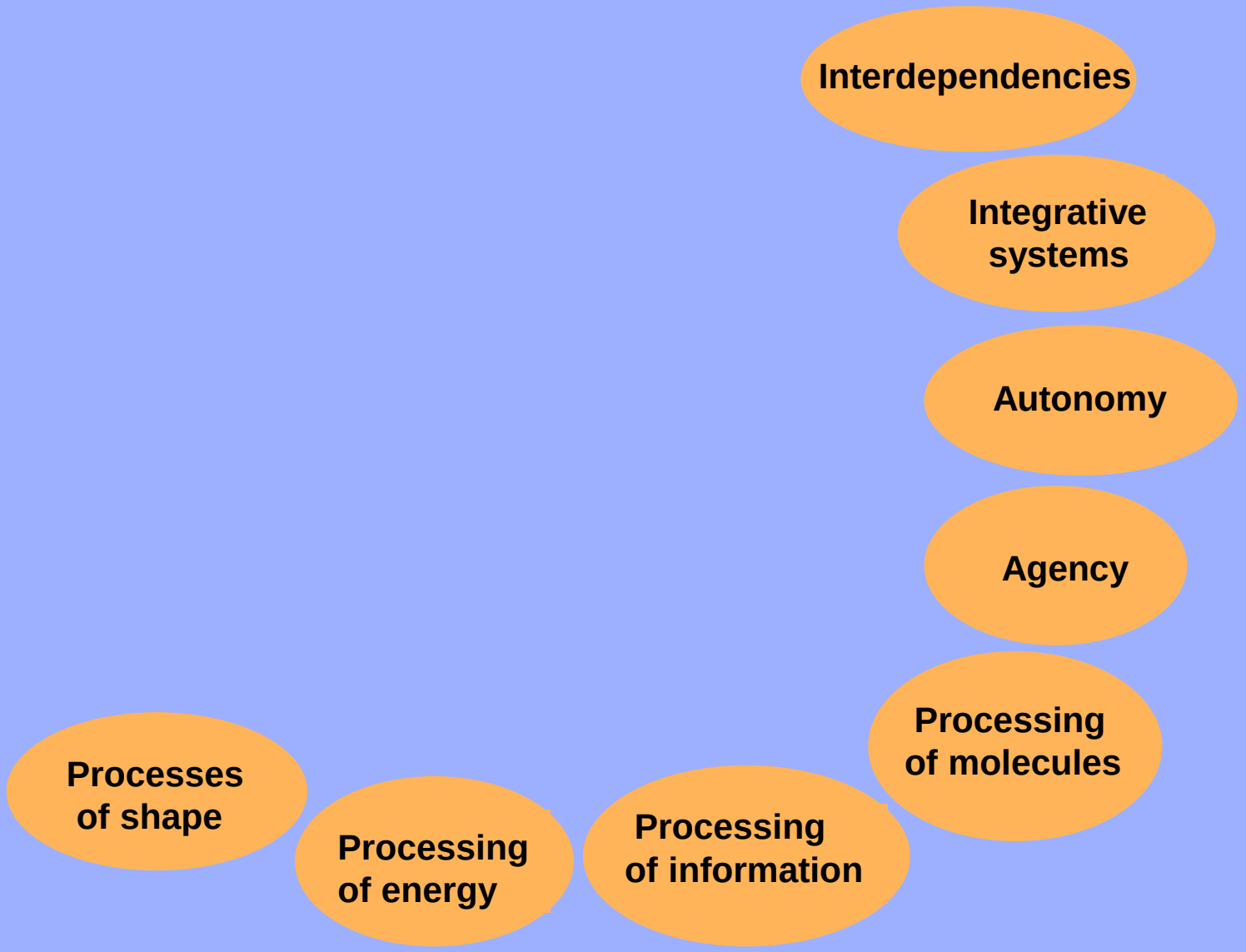


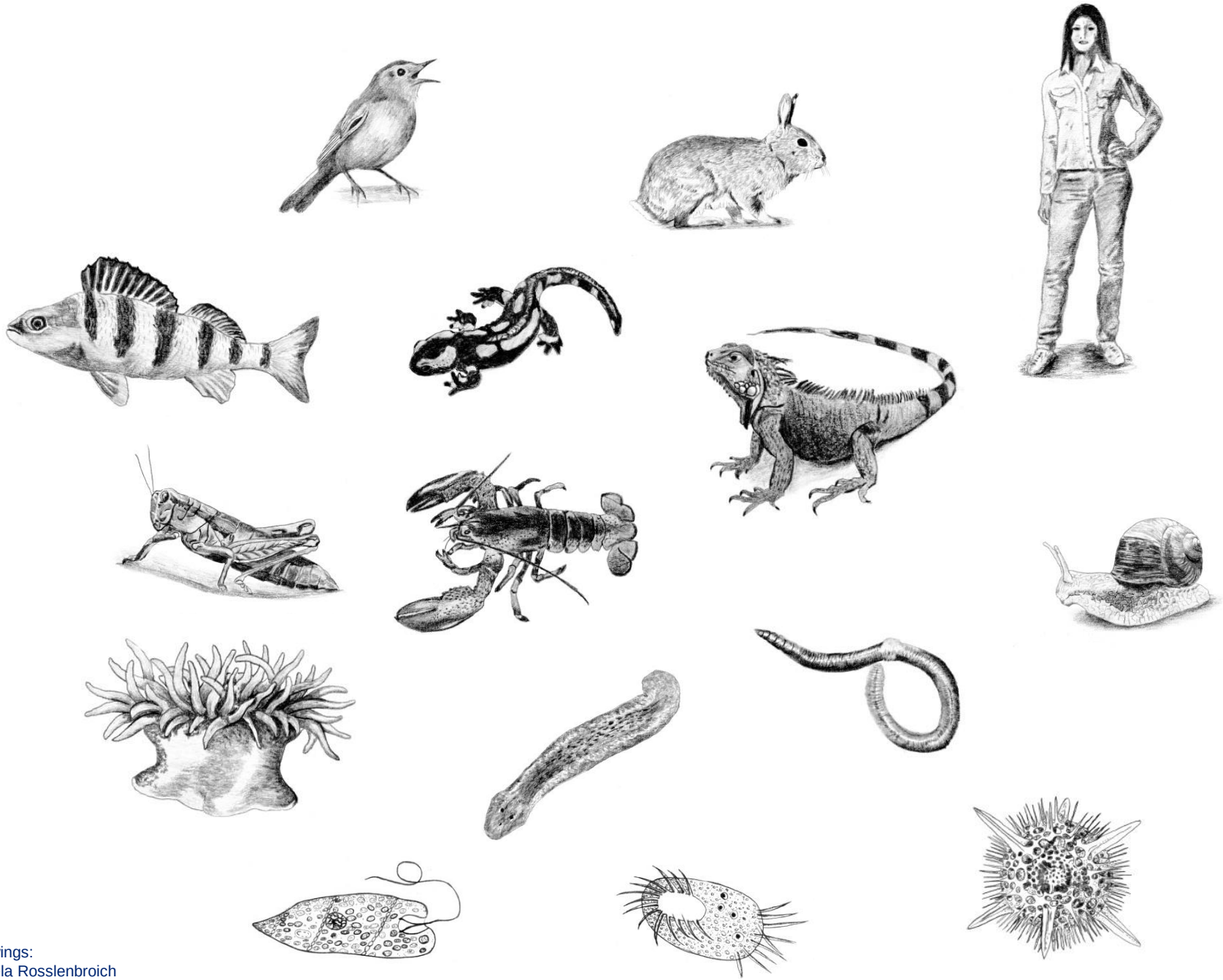
Rosslenbroich B, Kümmell S, Bembé B (2024):
Agency as an inherent property of living organisms.
Biological Theory. https://doi.org/10.1007/s13752-024-00471-7


Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules

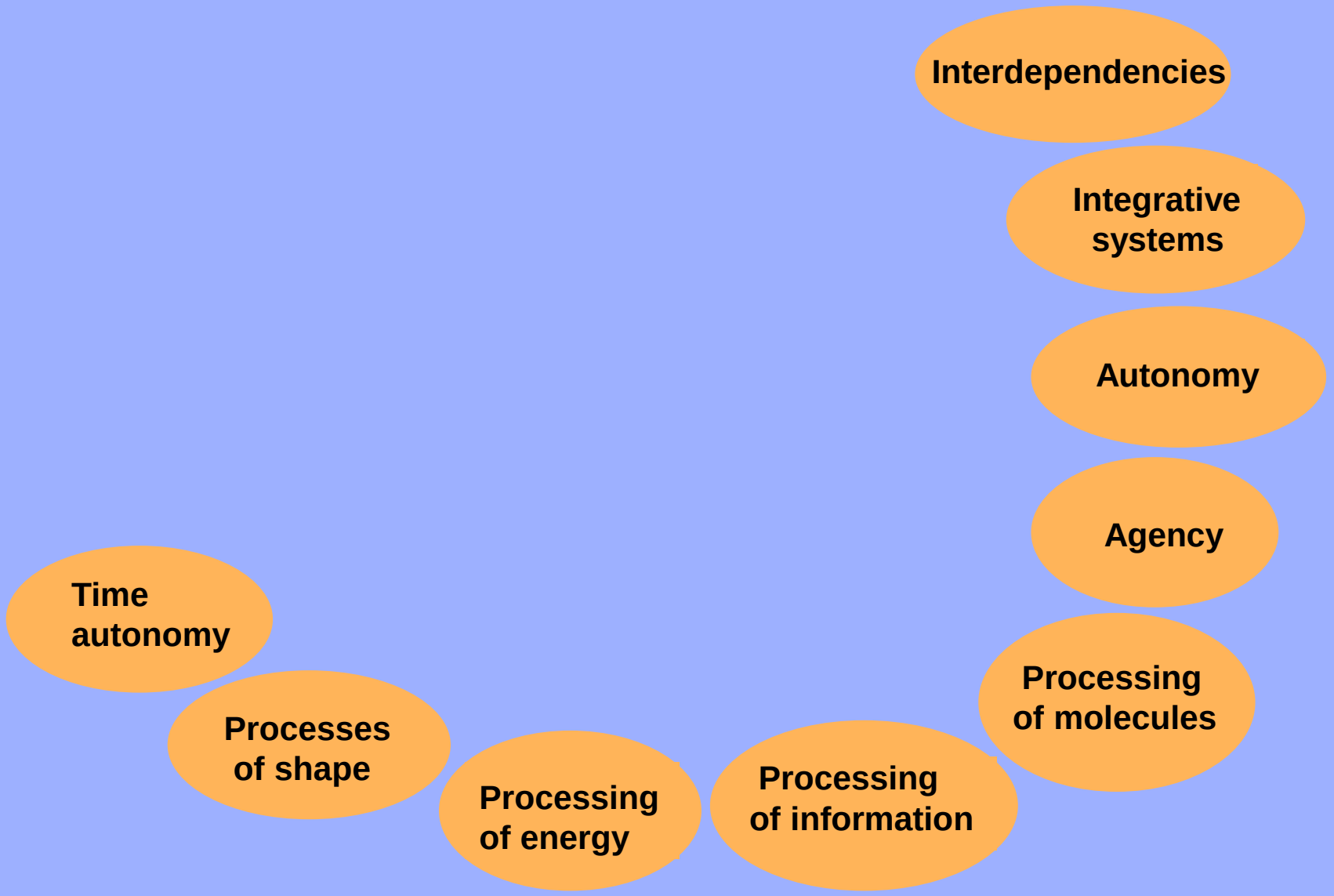

Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information

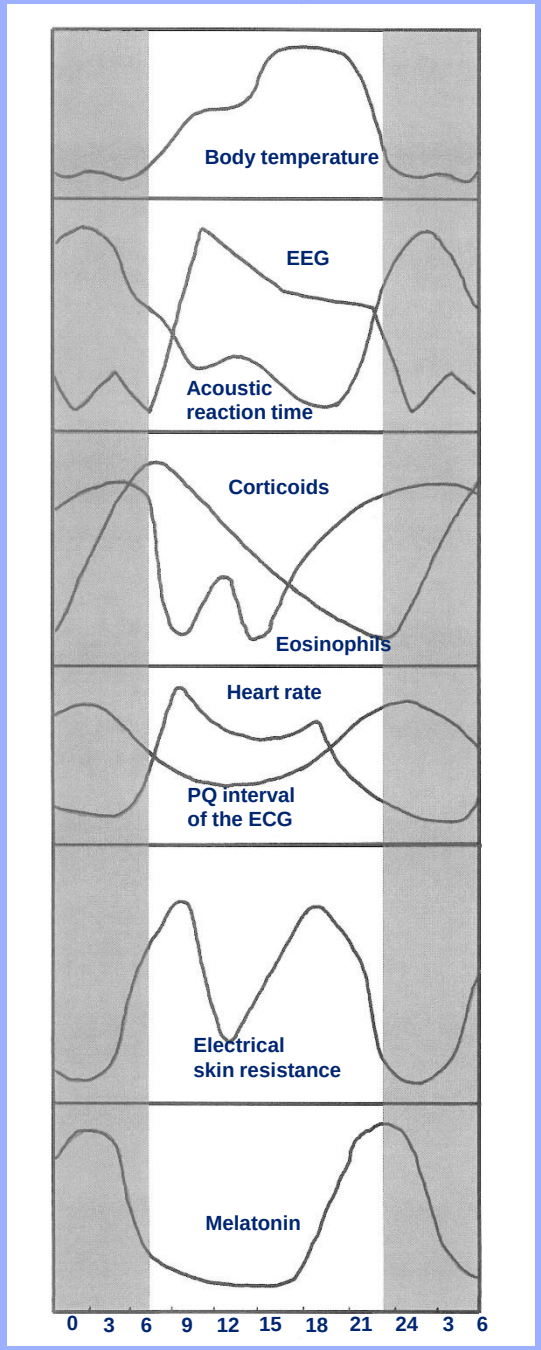

Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information
Processing of energy


Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information
Processing of energy
Processes of shape

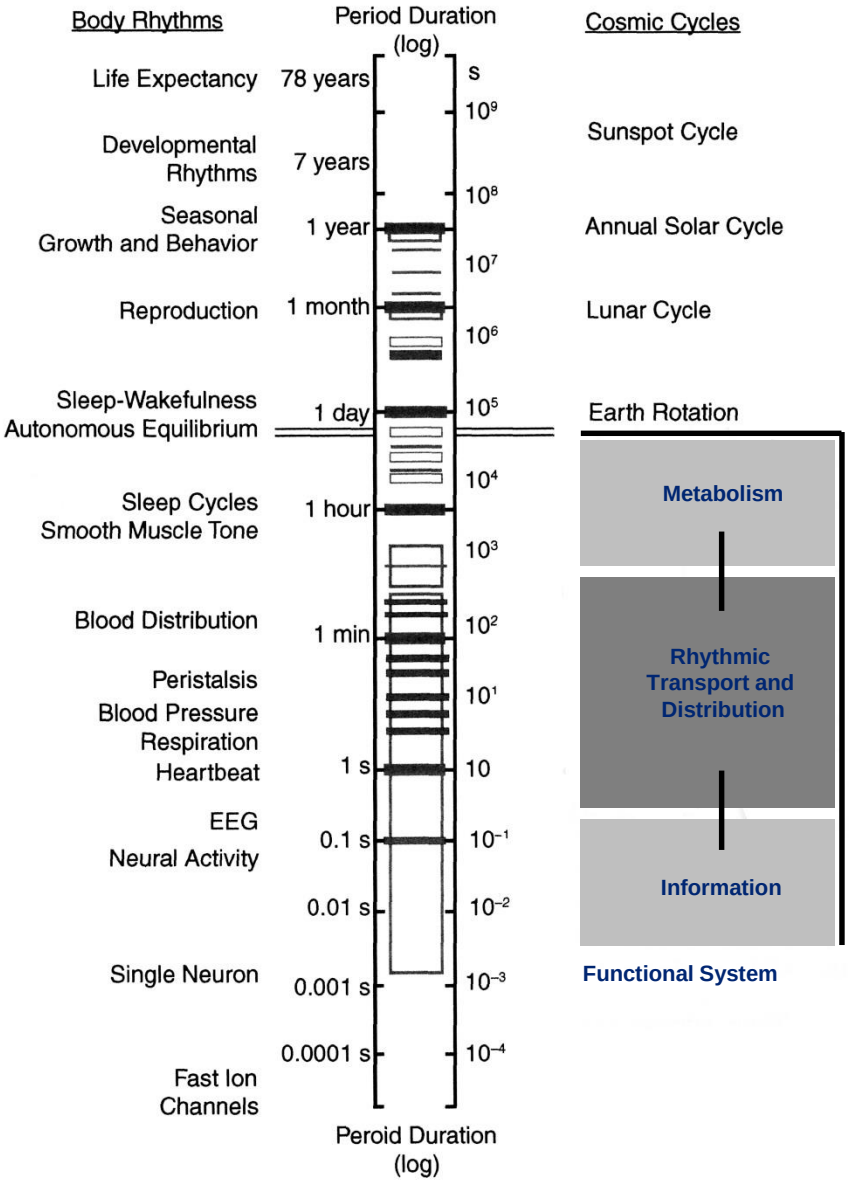


Drawings:
Angela Rosslenbroich

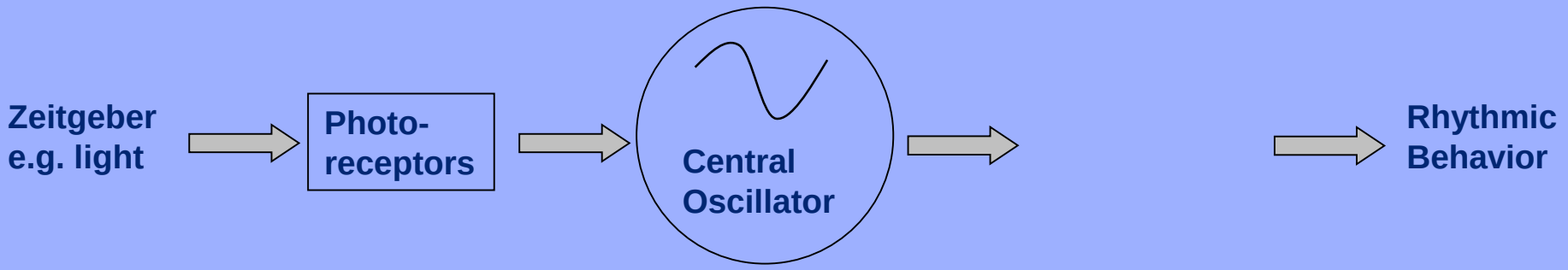

Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information
Processing of energy
Processes of shape
Time autonomy

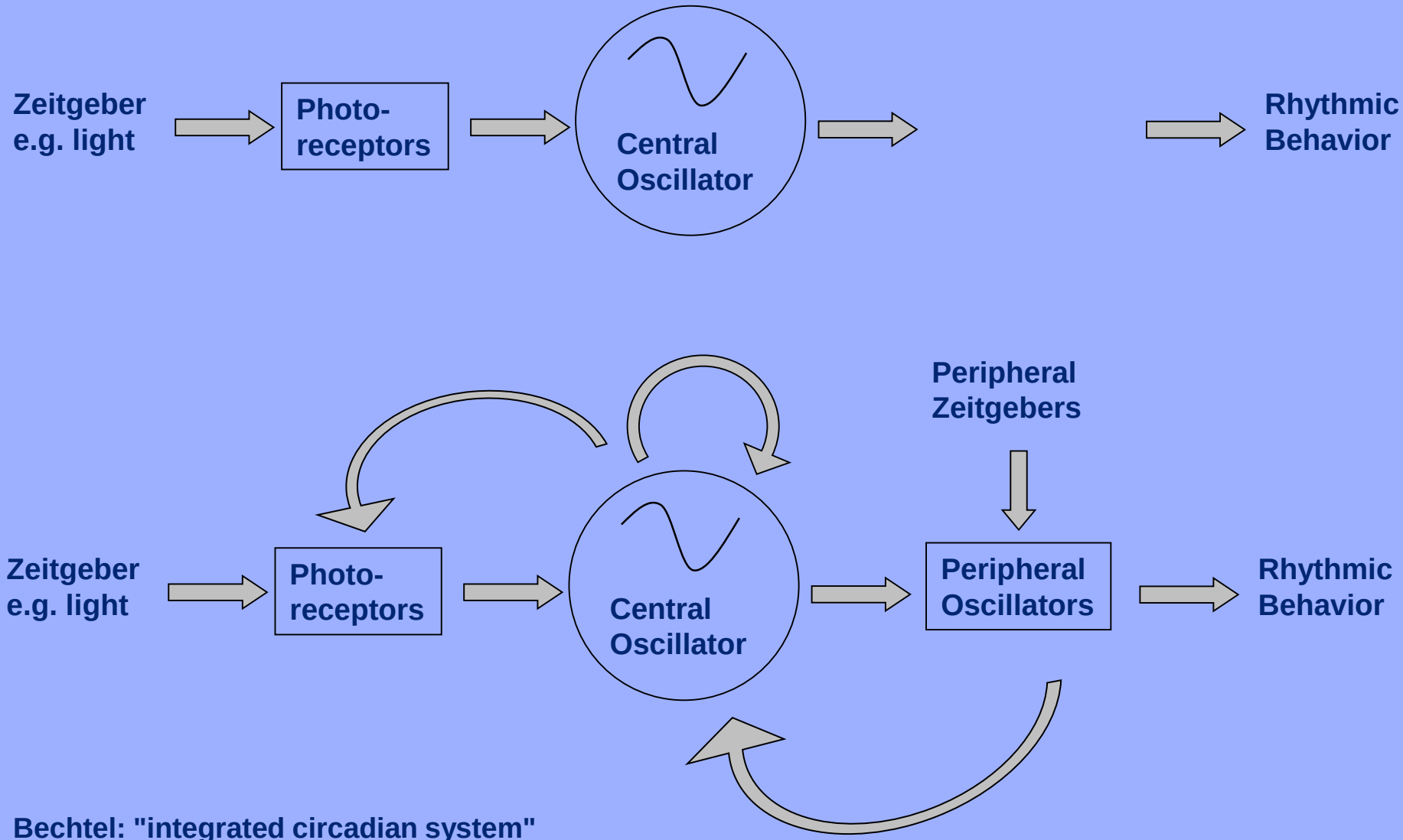


Human circadian rhythms



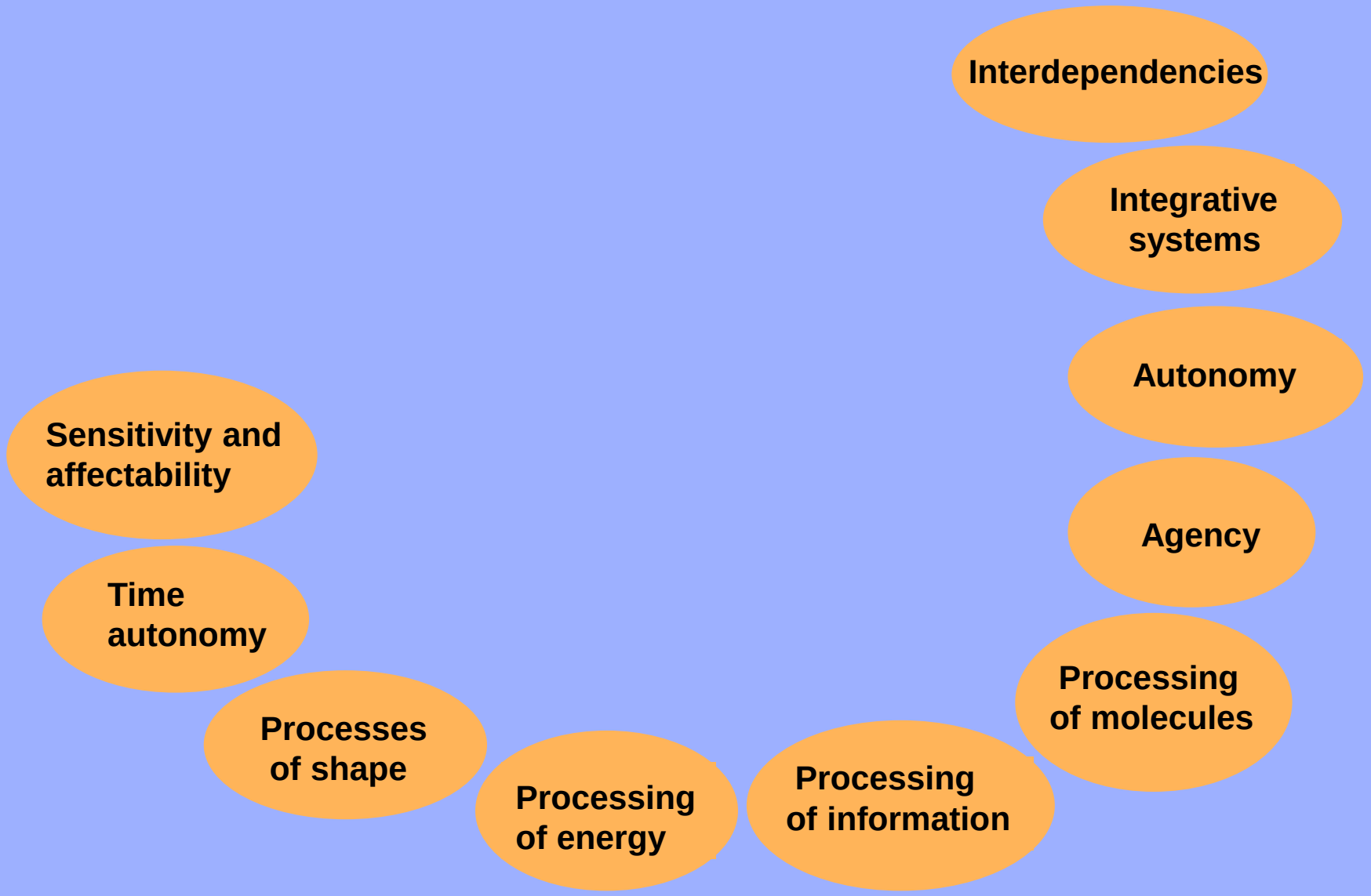
The spectrum of human biological rhythms, according to Gunther Hildebrandt. Moser et al. (2008)

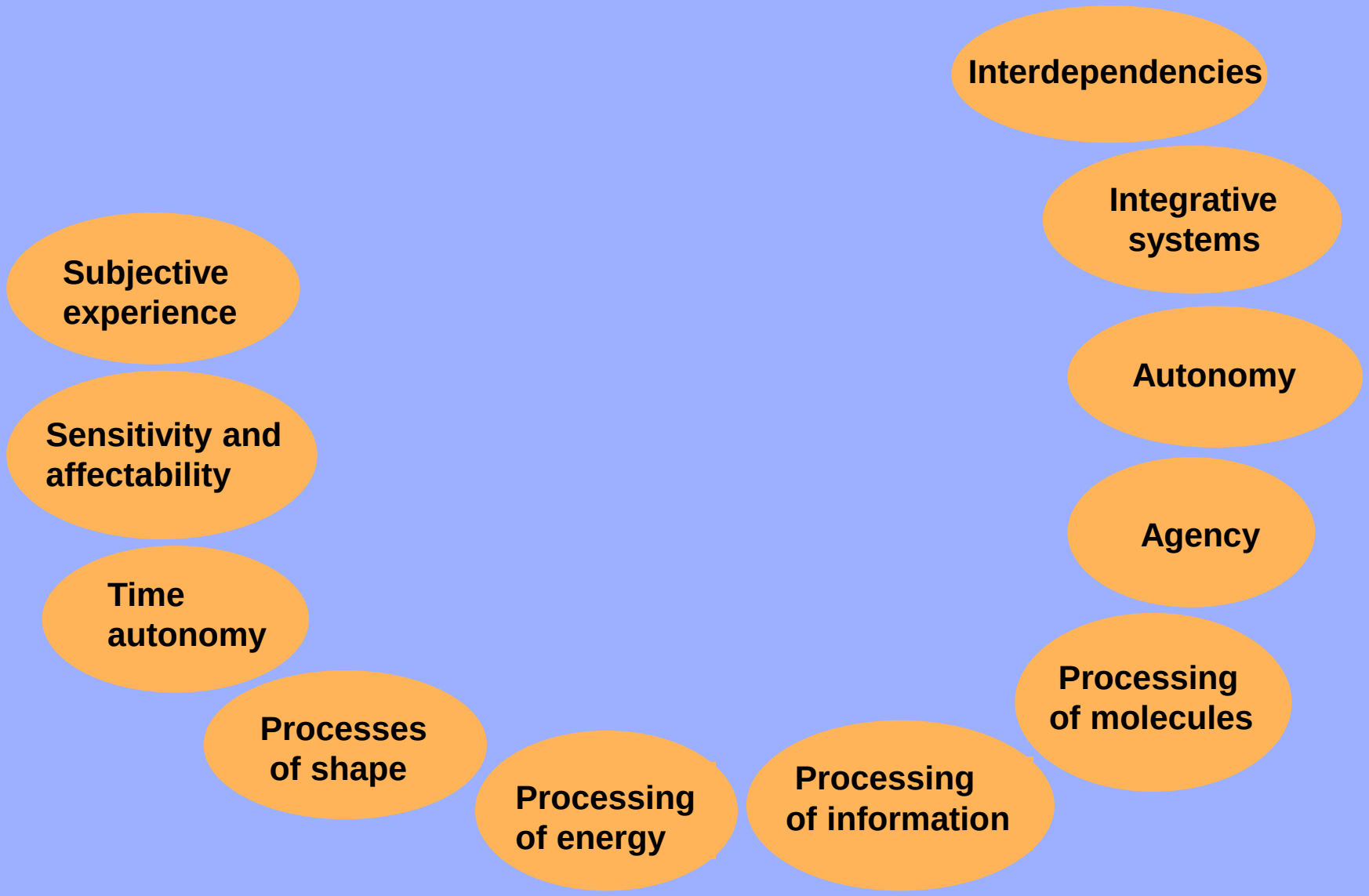

Zeitgeber
e.g. light
Photo-
receptors
Central
Oscillator
Rhythmic
Behavior

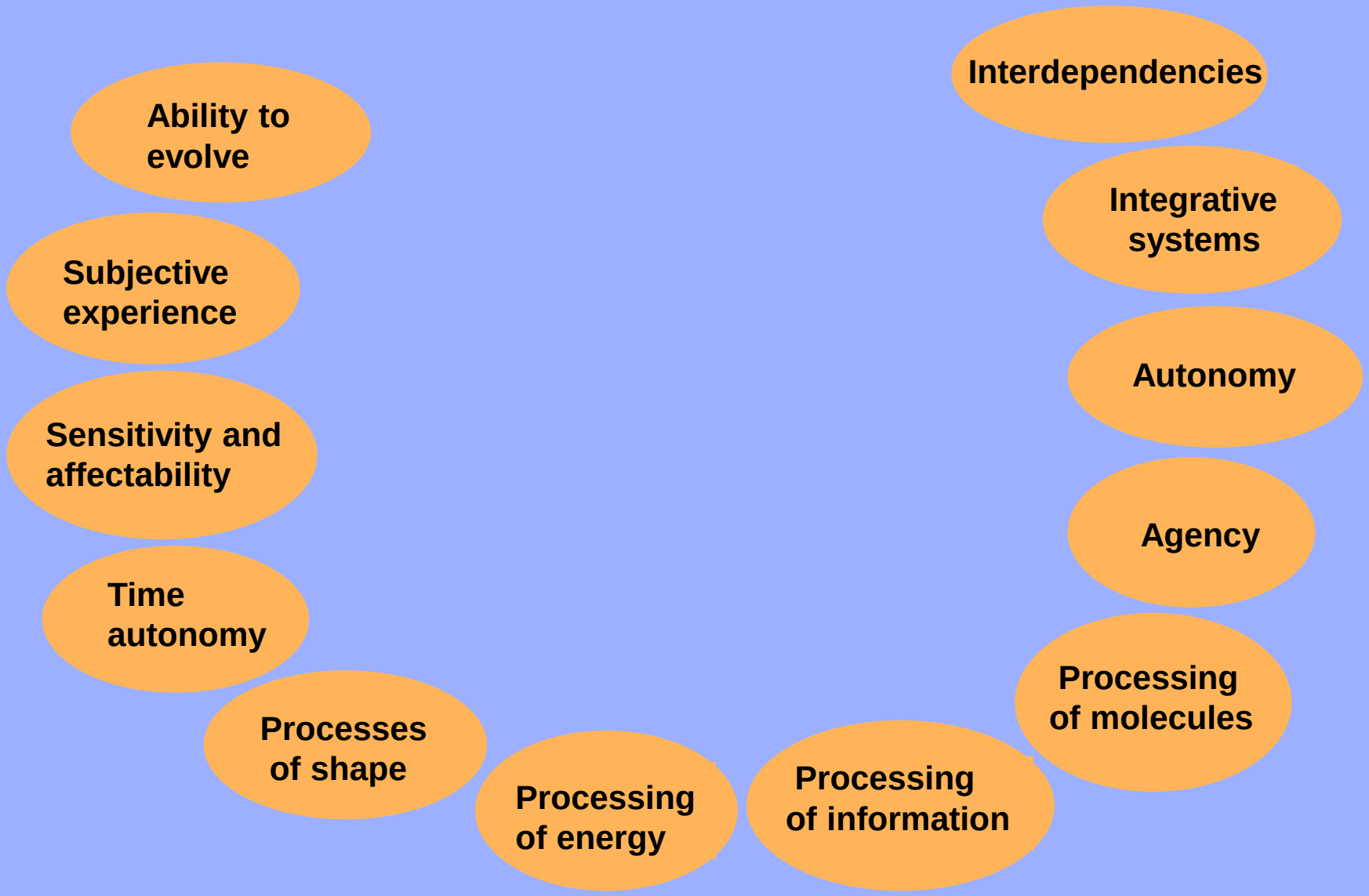


Bechtel: "integrated circadian system"

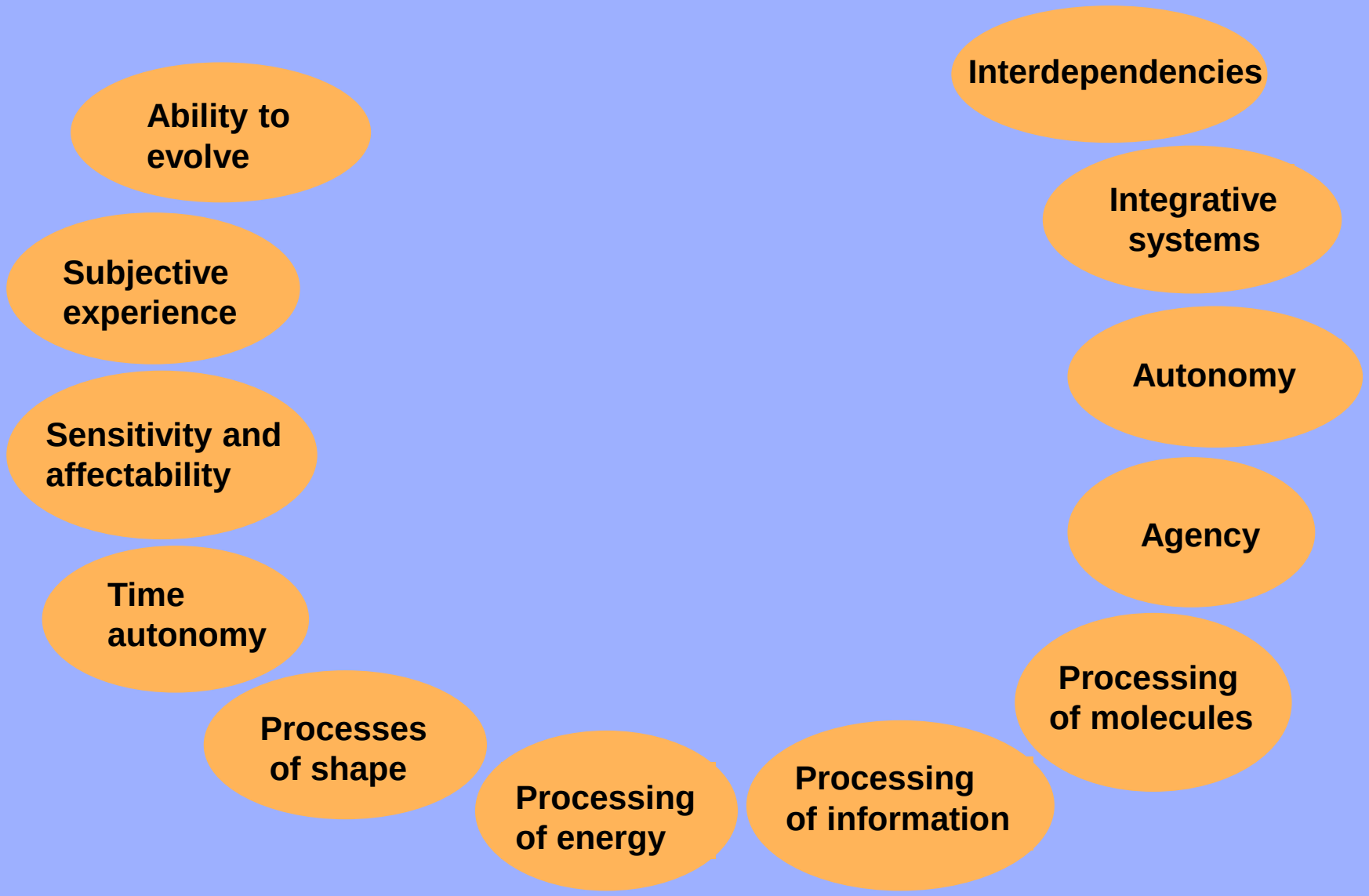
Bechtel W (2010): The downs and ups of mechanistic research: circadian rhythm research as an exemplar. Erkenntnis 73, 313-328

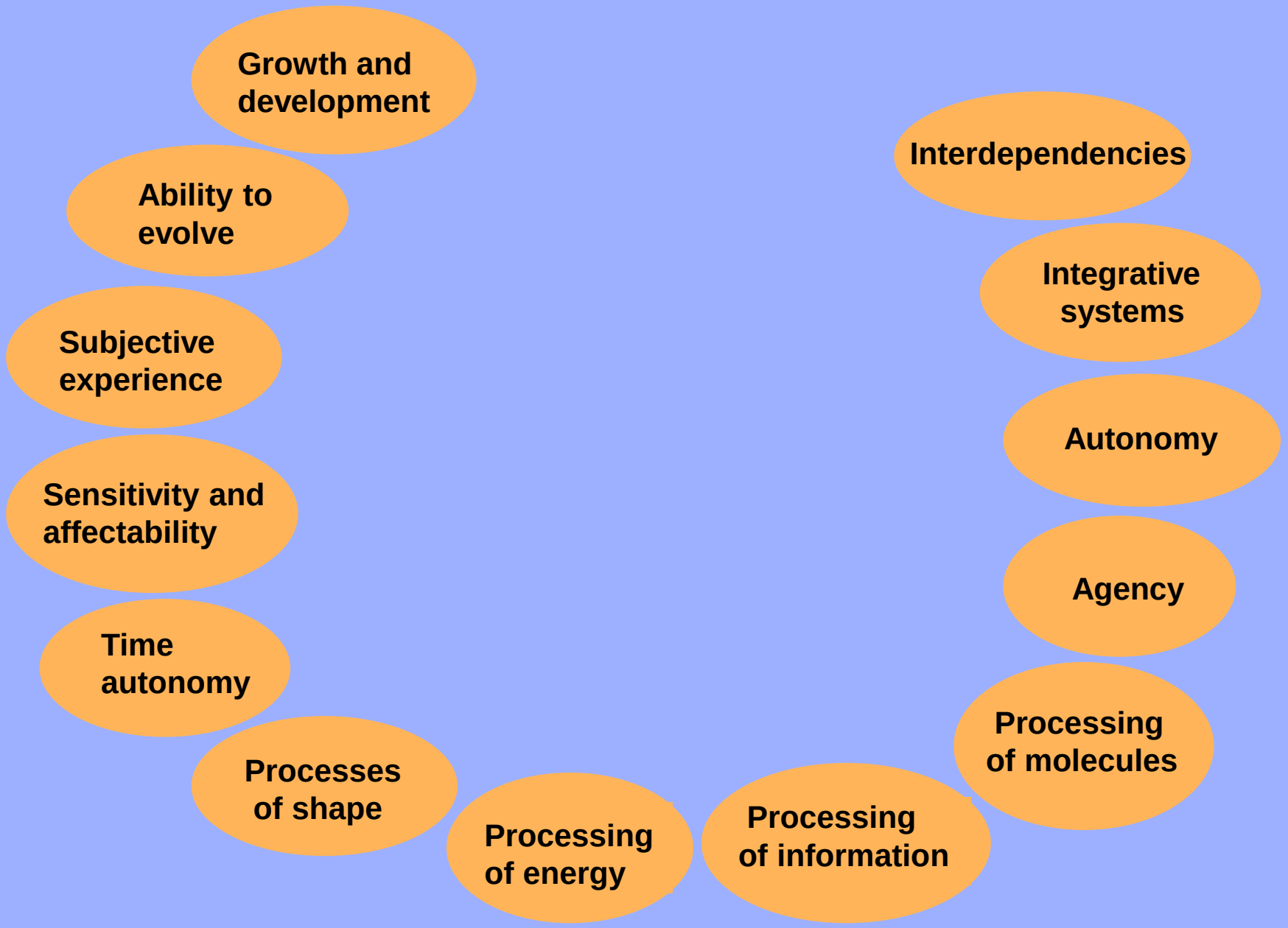

Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information
Processing of energy
Processes of shape
Time autonomy
Sensitivity and affectability

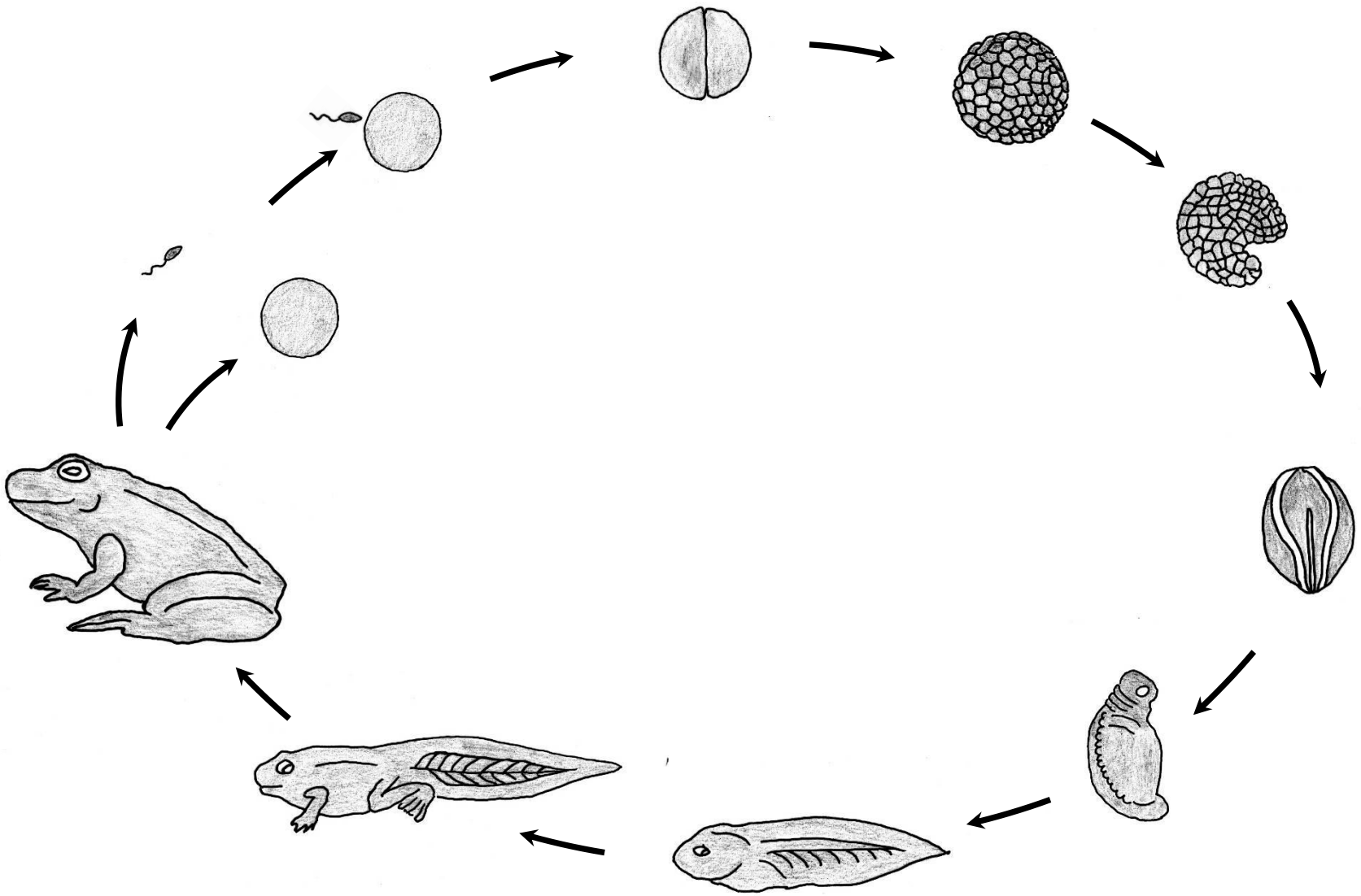

Interdependencies
Integrative systems
Autonomy
Agency
Processing of molecules
Processing of information
Processing of energy
Processes of shape
Time autonomy
Sensitivity and affectability
Subjective experience


Ability to evolve
Subjective experience
Sensitivity and affectability
Time autonomy
Processes of shape
Processing of energy
Processing of information
Processing of molecules
Agency
Autonomy
Integrative systems
Interdependencies

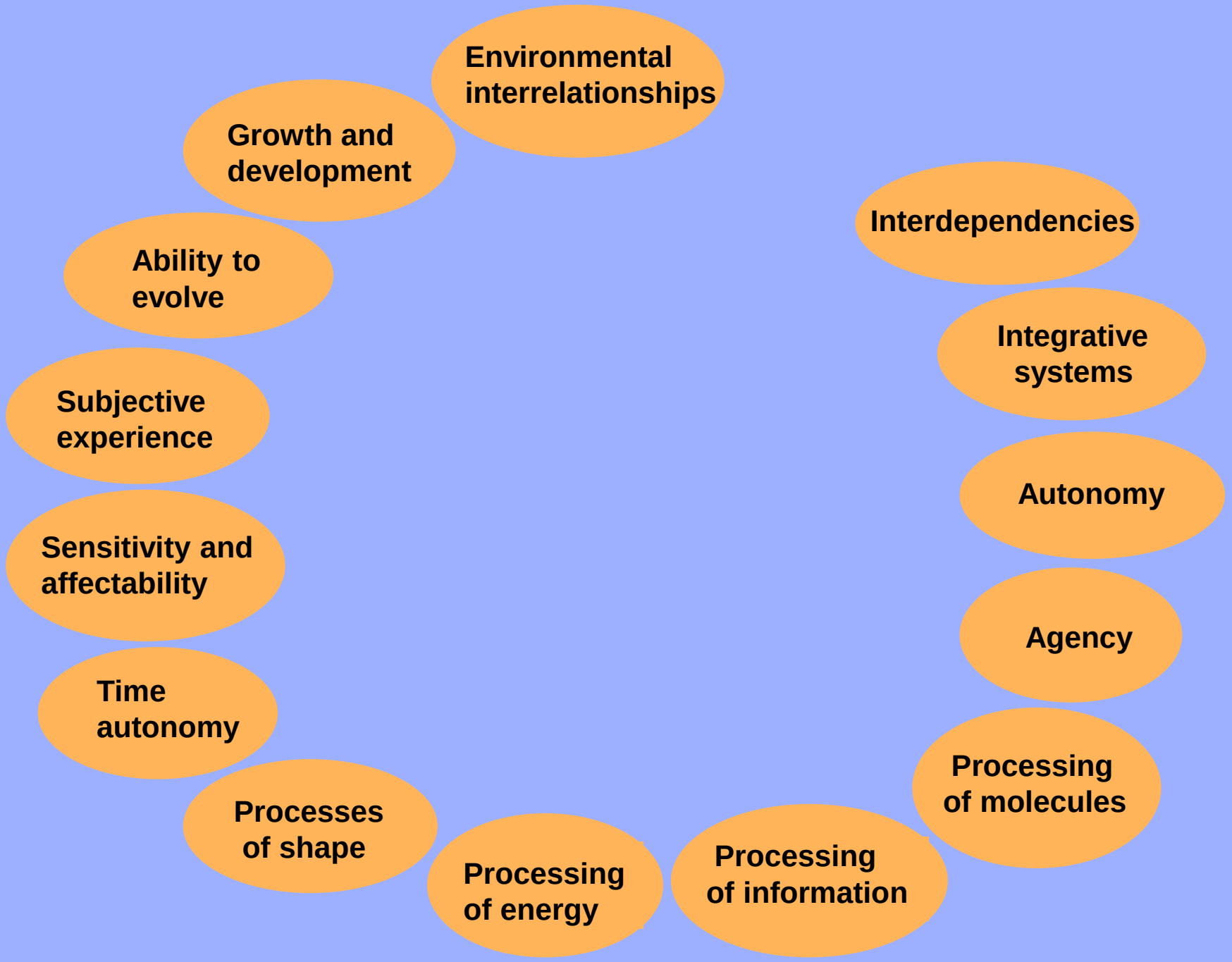
www.thethirdwayofevolution.com

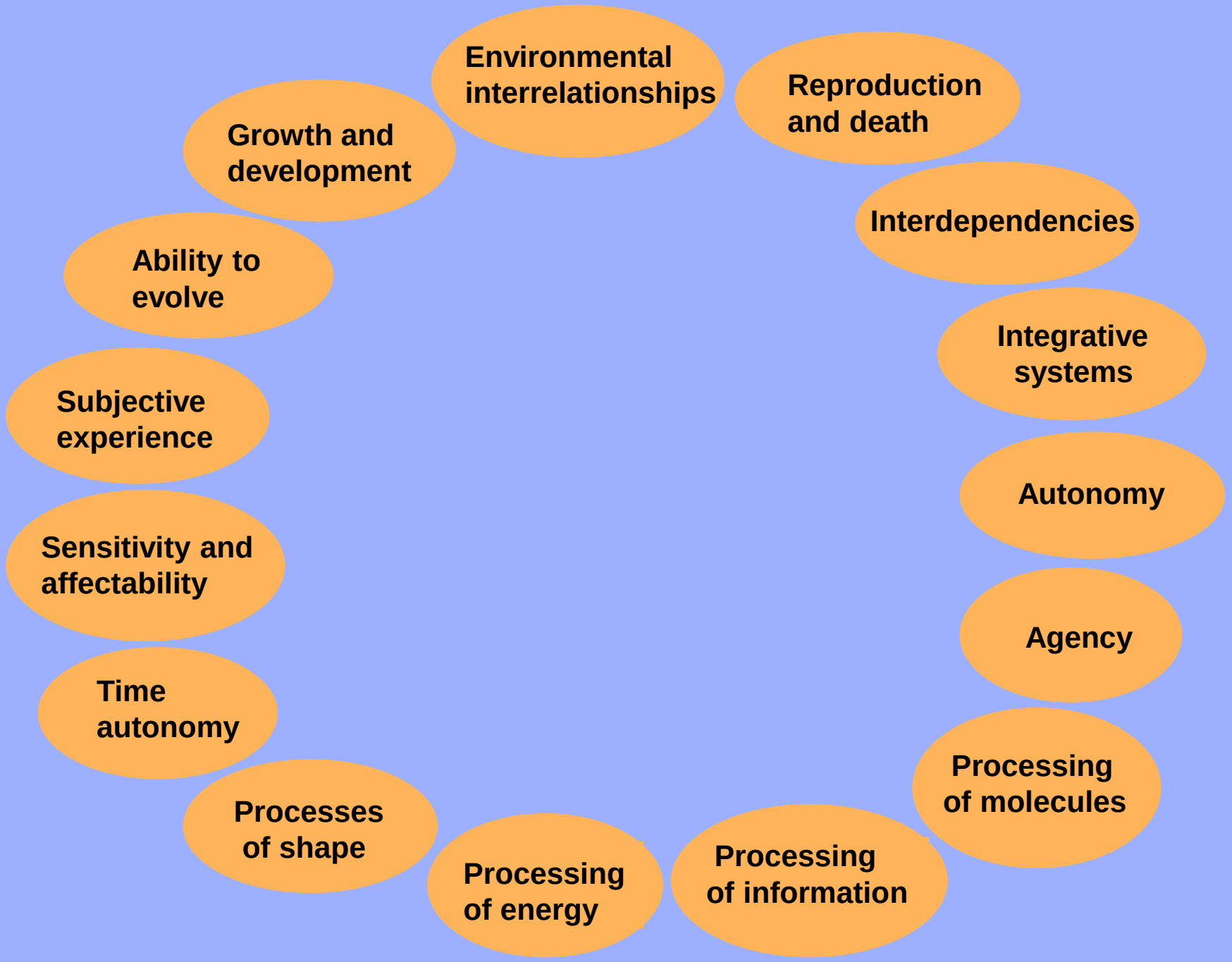



Growth and development
Ability to evolve
Subjective experience
Sensitivity and affectability
Time autonomy
Processes of shape
Processing of energy
Processing of information
Processing of molecules
Agency
Autonomy
Integrative systems
Interdependencies



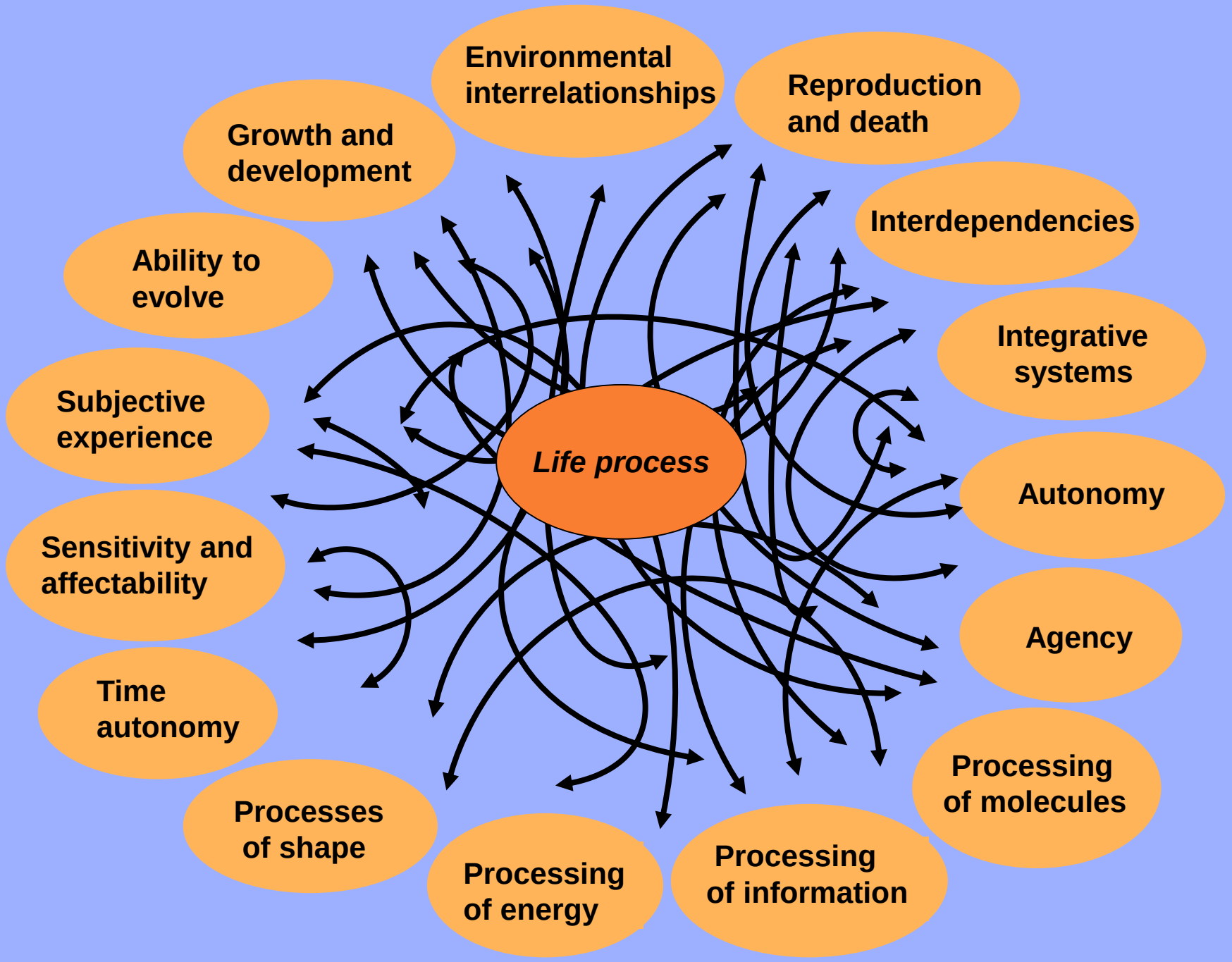



Environmental interrelationships
Growth and development
Ability to evolve
Subjective experience
Sensitivity and affectability
Time autonomy
Processes of shape
Processing of energy
Processing of information
Processing of molecules
Agency
Autonomy
Integrative systems
Interdependencies


Environmental interrelationships
Reproduction and death
Growth and development
Interdependencies
Ability to evolve
Integrative systems
Subjective experience
Autonomy
Sensitivity and affectability
Agency
Time autonomy
Processing of molecules
Processes of shape
Processing of information
Processing of energy

Nature's "spectacle is always new, because she always creates a new audience. Life is her most beautiful invention, and death is her artifice to have abundant life."

Johann Wolfgang von Goethe


Environmental interrelationships
Reproduction and death
Growth and development
Interdependencies
Ability to evolve
Integrative systems
Subjective experience
Life process
Autonomy
Sensitivity and affectability
Agency
Time autonomy
Processing of molecules
Processes of shape
Processing of energy
Processing of information



Sandregenpfeifer (istockphoto – EstuaryPig)

universität Witten/Herdecke

Institut für Evolutionsbiologie und Morphologie

Rosslenbroich B, Kümmell S, Bembé B (2024): **Agency as an inherent property of living organisms**. Biological Theory. https://doi.org/10.1007/s13752-024-00471-7

Rosslenbroich B (2023): **Properties of Life – Toward a Theory of Organismic Biology.** MIT Press

Rosslenbroich B (2016): **Properties of Life: Toward a Coherent Understanding of the Organism**. Acta Biotheoretica 64, 277-307

Rosslenbroich B (2014): **On the Origin of Autonomy. A New Look at the Major Transitions in Evolution**. Springer