# Level 4

# Systems of Populations as *Symbiosis of Agents*

Studies of systemic biology must not be restricted onto the cellular level — after all, another class of truly challenging biological phenomena concern *populations.* One needs systemic means to understand the superposition of individual actions. Today's understanding of *ecologies* is surveyed, for example, in [48].

Again, abstracting away details gives statistical models capturing the population properties in the large. There exists a wealth of first-principles models that are tailored to explicitly explain certain ecology-level phenomena (for example, see [57]). However, applying the straightforward modeling principles and letting them cumulate, the originally simple (nonlinear) formulas soon become very complicated, and the value of the models becomes compromised. One should keep in mind that it is individuals only that exist, giving rise to the emergent properties: It can be claimed that without taking the actors into account gives incorrect intuitions. Not whatever simplifications are appropriate when modeling populations — again, it is the neocybernetic principles that should be applied. This time the model structures already exist, and the "off-the-shelf" models can be directly exploited.

Neocybernetics offers tools to capture the population-level global properties that emerge from local interactions. It has been said that ecology is systemic biology; now one can reach towards *systemic ecology.* Ecosystems with the same underlying principles also exist outside the boundaries of conventional biological thinking, and examples are presented from other fields to perhaps reach interesting cross-fertilization among disciplines.

## 4.1 Extending from a domain to another

In the previous chapters, concrete examples were studied in a bottom-up fashion, finding holistic views characterizing the system-level phenomena. Now when the concepts have intuitive substance and content, it is possible to continue the studies in other domains, exploiting the same understanding, without any more

Figure 4.1: It is the neighboring systems (agents) that *are* the observed environment (graphics by Maurits Escher)

going into details. There now exists understanding about the crucial nature of complex feedback structures within the system: One does not need to know exactly how they are implemented — but to maintain the system integrity *they just have to exist there.*

### 4.1.1 Environment seen as neighbors

How to define a *system?* It has been said that the most complete definition can only be such that

> 'system" is a *system.*

This "definition" employs our intuitive understanding — what can be seen as a relevant entity, functionally consistent host of dynamic attractors, can be seen as a system of its own. It can be claimed that all other definitions of system are too narrow, and would not cover all aspects of the idea. However, such heuristics is a challenge to the traditional systems thinking.

Traditionally when analyzing systems, it is the system boundary that is perhaps the most important thing to characterize: The boundaries separate the "inside" (the system) from the "outside" (non-system). According to the selection of these boundaries, variables coming from outside are seen as input signals. When doing neocybernetic modeling, however, even the basic conventions are changed: The systems and their boundaries become relative, dependent of the point of view. Now *there is no separate environment* — when the feedbacks are seen as an integral part of cybernetic systems, environment becomes an essential part of the whole, the system properties being determined together by the environment and the actual system. As John Donne almost said, "no system is an island".

The purpose here is to extend the studies from the realm of inner-system phenomena onto the environment. In principle, one is stepping from the (assumedly) known into the unknown; however, it turns out that it is the same ideas that hold inside and outside. One could say that *somebody's environment is somebody else* — it is other (more or less) similar systems that are found outside. The neocybernetic model formulas are reciprocal and they can be inverted quite formally without changing their structure — the "inside" becoming the "outside", and *vice versa.* One only turns from studying a single system towards studying a set of such individuals. The system's "inputs" are (mainly) neighboring systems' state variables, and *vice versa.* Indeed, when the internal structure of the combination of systems becomes more complicated containing more variables, the *actual* independent inputs coming from the outer world are less visible than the "internal inputs" (see Fig. 4.1).

The uniqueness of the system boundaries becomes challenged also in other ways. Traditionally it is hierarchies of systems that are used to structure complex domains, but now one cannot determine a hierarchy of subsystems in an unambiguous way — the appropriate structure depends on the point of view, depending on the level of accuracy, and the selection of variables. A single subsystem can concentrate on a single functionality, or it can take care of more functionalities — that is, $n$ can be 1 or higher — no matter how the boundaries are selected, self-organization reconstructs the functional structure according to the signal properties, the same (linear) principles operate on all scales.

Assume that each cell stands for a single functionality only, the functionalities being different for all cells. Further assume that diffusion distributes the signals (chemical concentrations) evenly among the cells. The system of subsystems finds its balance, the subsystems exhausting each other's "waste products". This is the simple basic scenario for explaining *symbiosis* — relevant functionalities are distributed among localized actors (in this case cells). It needs to be recognized that there is no "negotiation" or higher level operation control needed: All cells just optimize their behaviors in their very local environment (and, indeed, the cells themselves do not even know they are carrying out some optimization).

More sophisticated structures of symbiosis are readily imagined. Assuming that each cell is alone responsible of only differential effects, it is the steady state values $\bar{x}_i$ that reveal the proportions of different functionalities, or cell types, that are needed to fulfill the environmental needs. When there exist individual cells sharing the same functionality, the capacity limitations are compensated by the high number of identical subsystems. The balance ratios of the numbers of representatives for different types are determined by the balance values $\bar{x}$. It is all about dynamic balance pursuit again.

The symbiotic "systems of systems" are characteristic also to more complex domains: From the level of individual cells one can get to the level of tissues and organs; from the level of individual organisms one can get to the level of populations; and from the level of species one can get to the level of ecosystems — what is more, the organisms and their systems can be physical or abstract. This kind of characterization is possible in principle. As the systems become more complicated, however, the signals and interactions become more abstract, and no conclusive models or predictions can be made. When escaping the immediate chemical domain, there is more freedom to construct the systems. Cognitive systems (symbiosis of neurons) will be studied in chapter 7, and the role of different views of the available information is studied in the chapters 5 and 6. Some ideas concerning symbiotic systems are presented below.

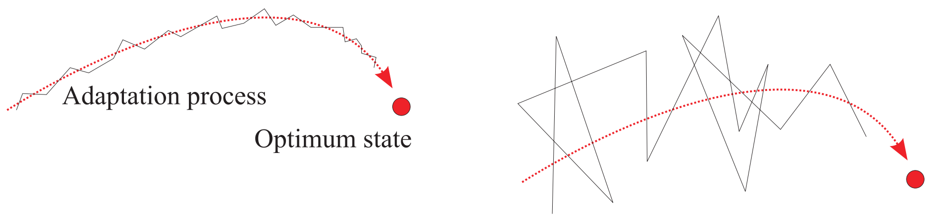


Figure 4.2: The adaptation strategies and dynamics can be very different in different kinds of systems — but the final state, the hypothetical optimum, is the same for all

### 4.1.2 From individuals to a population

When extending the analyses from symbiosis of cells to symbiosis of populations, in principle, it is easy to reinterpret the symbols: The vector $\bar{x}$ represents *population sizes,* $\bar{u}$ is the vector of *available resources* (different types of food and other living conditions), and matrices $A$ and $B$ contain the *interaction factors* (competition) among populations. The columns in $\phi$ can be called *forage profiles,* exploitation conventions corresponding to the populations. But is this more than renaming? Are the very different systems really analogous? And, after all — is there universality among complex systems?

When abandoning the familiar domains, all points of support seem to be lost: If studying distinct organisms, the chemical cues, for example, can be completely secondary when the interactions become implemented. As the environment is seen as consisting of individual subsystems, it is no more mere signals that can be measured in the environment; the higher one gets in the hierarchy of systems, the more the inputs become more and more abstract *functions,* as it is the functionalities $\bar{x}_i$ that are used as inputs $\bar{u}_j$. It is assumed that such functions offered by the environment (or *need* of functions as requested by the environment) can somehow be quantified. In any case, it is the basic intuitions that remain: There must again exists the same kinds of underlying principles to make the emergence of organization from non-controlled local behaviors possible — there must be common pursuit for survival shared by all agents. But there can exist many alternative ways to survive in the environment — why should one favor one specific model structure?

The key point is that *following the neocybernetic model, there is evolutionary advantage.* It turns out that *optimality in terms of resource usage is reached,* meaning that surviving, successfully competing natural populations assumedly must have adopted this strategy. As soon as the coupling coefficient $q$ in a system reaches the threshold in (as discussed in chapter 3), there exists a clear evolutionary gradient visible towards the optimum. This all is mathematically very simple, and as long as the neocybernetic strategy is the only known route to self-organized principal subspace analysis, it can be claimed that there exist no competing theories. In the long run, it is the models that implement the PCS model that can best be matched against variations in the resources $\bar{u}$ (in terms of quadratic variation criteria), resulting in most efficient exploitation of the resources. And populations with optimal strategies outperform others in terms of biomass and more probable survival.

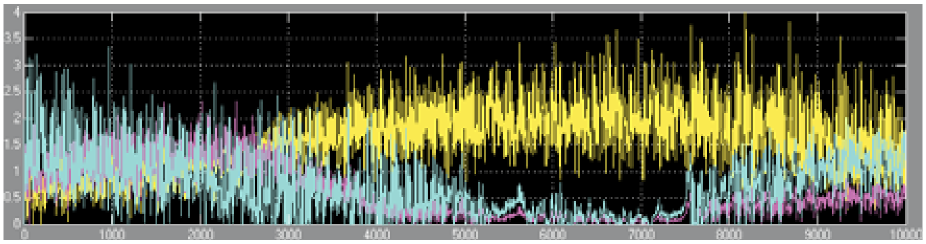


Figure 4.3: A typical simulation illustrating the behaviors of three (hypothetical) competing species (in arbitrary units). The environmental conditions, or resources in the vector $u$, are random but have a certain statistical distribution, and the populations $\bar{x}$ are assumed to instantaneously follow the changes. Population sizes below zero are simply zeroed during adaptation — finally this results in emergence of populations remaining always positive-valued

In the framework of resources and their exhaustion, "power transfer" between systems can be made concrete: It is assumed that the product of consumed resource and produced activity has the dimension of power, as being reflected in reproduction capability. — Of course, the whole theory collapses if there are no variations in the signals, if studying static environments. In such a case no strategy can be claimed to outperform the others; these issues are studied on Level 5.

It is perhaps hard to believe that the very nonlinear genetic mutations and accommodation processes, etc., would have anything in common with the cellular adaptation details. How could the same model apply? The key observation here is that it is, again, only the dynamic equilibria that are studied, not the all possible routes there. Whereas the adaptation processes can be very complicated and varied, the final emergent optimum can be unique in terms of tensions (see Fig. 4.2). When concentrating on the balance only, it is also the dimensionality of the problem that goes down, making the optimization process feasible. And, remembering the previous chapter, it is the "interfaces", common variables between interacting systems only that count.

### 4.1.3 Properties of a cybernetic population

Traditionally, ecological models concentrate only on a single species or interactions between two species (for example, see [79]). Larger models try to characterize the *niches,* implementing explicit *forage profiles* that describe the resource specifications for each species [75]. However, such models for complete ecologies need careful tuning; evolutionary strategies typically become unstable, meaning that most of the species become extinct, only some of them prospering and exhausting all resources.

When applying the neocybernetic model, ecosystem simulations remain stable even though the dynamics looks "naturally chaotic": There exists unforced dynamics in different time scales (see Fig. 4.3). Adaptation in the system is based on cybernetic evolution — there is vivid dynamics, but no explosions take place. Rapid stochastic variations in the population are followed by slow long-term behaviors. No fine tuning is needed: If there is enough variation in the resources, after system-wide adaptation a balance is found where there is a "niche" for every species. The niches are characterized by the principal subspace dimensions, the forage profiles $\phi_i$ mapping from the prevailing resource vector $\bar{u}$ to the balance population $\bar{x}_i$. The roles of the species cannot be predicted, only the subspace that is spanned by all of them together is determined by the environment. The key observations concerning the neocybernetic model properties can be summarized:

- **Robustness.** In nature, no catastrophic effects typically take place; even key species are substituted if they become extinct, after a somewhat turbulent period. Using the neocybernetic model, this can also be explained in terms of the principal subspace: If the profiles are almost orthogonal, in the spirit of PCA, changes in some of the latent variables are independent of each other, and disturbances do not cumulate. Also because of the principal subspace, sensitivity towards random variations that are not supported by the long-term signal properties are suppressed.

- **Biodiversity.** In nature, there are many competing species, none of them becoming extinct; modeling this phenomenon seems to be extremely difficult (see [89]). Now, again, this results from the principal subspace nature of the model: As long as there exist various degrees of freedom in input, there is reason for different populations. Within species, this also explains why in balance there exists variation within populations as the lesser principal components also exist (compare to the *Hardy-Weinberg law:* "In a large, random-mating population, the proportions of genes tend to remain constant from generation to generation").

### 4.1.4 "Complete-information ecosystems"

Regardless of the uniqueness assumption concerning the optimum state, practical manifestations of the underlying dynamic balances vary a lot: What kind of populations will exist is not only dependent of the environment, but it also depends on the physical constraints. In nonlinear systems it is not only the final balance that is relevant — the route towards the optimum makes a difference, as the process can end in local minima. As will be discussed on Levels 5 and 6, it is the availability of information that makes a difference, and nonlinearities can often be interpreted in terms of different kinds of information blockages. For example, how the information theoretically motivated resource variation coverage is carried out in an ecosystem, depends on what kind of species are available — information cannot cross the species-wise genetic pools at the same rate. All these blockages together give rise to non-logical outcomes even in the equilibrium. During this chapter, however, complete availability of information is assumed. In practice, this means free mobility and information transfer among the signal carriers within a specific phenosphere.

It turns out that from the simplest chemical levels, it is easiest to skip all the intermediate levels (tissues, organs) directly to the most challenging levels, to the least structured ones, consisting of populations of more or less "intelligent agents", where complete information exploitation can be assumed. The intermediate levels necessitate more explicit structures, or *differentiation* among populations, and nonlinearities are necessary, as will be studied on Level 6.

The knowledge is also assumed to be shared equally by all actors in the system. It is assumed that all members of the populations can recognize all resources, and their weighting of different types of resources is similar. Whether this can be assumed or not in natural populations is to remain an open question here — but, again, when seeing ecosystems in a wider perspective, fruitful analyses can be continued.

It turns out that ecosystems need not be ecological — they can also be *economical.* There are attempts to apply holistic thinking to economy (for example, see [76]) — however, those models are constructed in the traditional way, bottom-up, trying to capture the system's properties in a collection of its parts, and a wider view is needed.

The above cybernetic discussions can somewhat directly be applied to market economy: Companies stand for species, and variables $\bar{x}_i$, or "population sizes", are company turnovers; input $\bar{u}_j$ is the available "benefit" in the product group, and the vector $\phi_i$ characterizing the company contains its production profile (other interpretations for the symbols are also possible). Individual humans are only "signal carriers", like ants in an ant colony. Strategies dictate the company-wise (or less wise) adaptation styles, as being manifested in economic decisions involving recruitment policy, investments, etc. Adaptation in a company is very nonlinear and non-continuous – however, if the company is to survive in the competition, the stochastic processes have to be more or less consistent in the long run, resulting in the balance determined by the environment. For example, the growing system stiffness becomes implemented in a natural way, new workers being employed if there is need for them, if there is work overload. From the point of view of the whole system it is statistically irrelevant how resources are distributed among the companies – however, for a single company, the details make a big difference: An individual company may prosper or suffer, or get extinct. Yet, in the case of bankruptcy, the system soon fills the niche with others companies.

What makes such an extension to a still more complex domain motivated, is the fact that *quantification of resources and efforts becomes easy* in abstract enough systems. In an economy, the universal measurement stick for "benefit" is *money.* All variables can be made structureless and dimensionless, all things become commeasurable when they are put on the money axis. When the role of money is generally accepted, and when the prices have been agreed upon, the cybernetic system can become more efficient, streamlined, and transparent. "Everything has its price" is the truth in an efficient economy; it is irrelevant whether or not this is ethically sustainable. One has to forget about morals: There is no "good" or "bad" in nature.

So, in principle, market economy operates like an ecosystem, and numerical analyses and simulations can be carried out. However, there also exist features in there that motivate a still wider scope. In different kinds of *memetic systems* one does not necessarily speak of money, but it is the same types of evaluations and assessments of alternatives that are being carried out, balancing between different kinds of visions of the reality. Such memetic systems include, for exam-

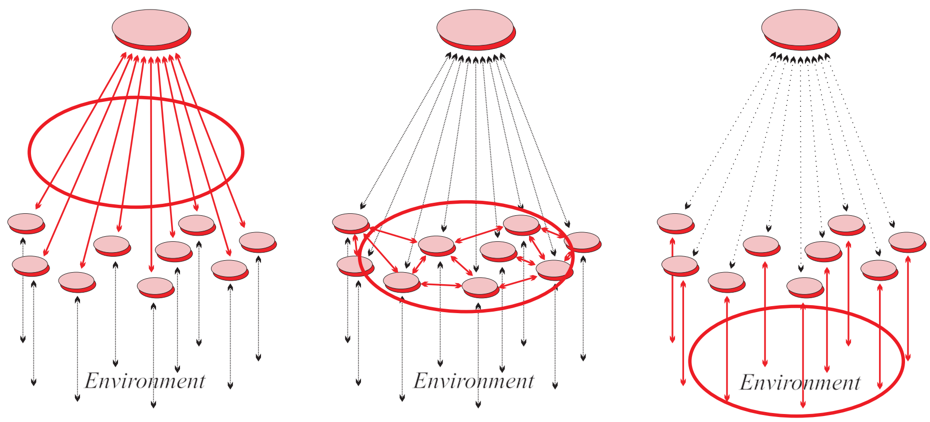


Figure 4.4: Communication and coordination among agents. The new view of differs not only from the centralized approach (on the left), but also from the traditional distribution, where the coordination is based on explicit communication (in the middle): Now the emphasis is exclusively on the environment (on the right)

ple, *scientific, social,* and *political* arenas. When politicians speak of "values", this should actually be taken in quite concrete terms: Everything can be traded, only the prices vary. Tensions in the systems are caused by contradicting aspirations. To understand such *constructivistic systems,* the role of the humans needs to be elaborated on.

## 4.2 Agent systems

There is a huge conceptual leap from a concrete domain — chemical signals, for example — to the domain of more or less *intentional* actors like animals or humans. Because of the intuitive differences, it is perhaps appropriate to speak of *agents,* when the signal carriers are functionally such independent entities with more or less "free will". The question is, again, very much about appropriate connotations. The discussions necessarily become very deep (for example, see [30] and [7].

### 4.2.1 Humans as agents

The agent paradigm has become popular as a framework for studies on distributed intelligent systems [67]. Today it is mostly about "software agents": The agents have been explicitly programmed to behave appropriately without centralized control [51]. To implement cooperation among the agents, complicated communication protocols and common *ontologies* are needed, and it is difficult to implement some adaptive behaviors in such systems. Now, on the other hand, one has trivial data-based ontologies and semantics: Everything important in data is buried simply in correlations between signals. There is no need for communication strategies, because the only interaction takes place in the form of feedback through the environment; indeed, there is a new view of seeing the structure of distributed systems (see Fig.4.4).

When extending the studies in the previous chapter to more or less intelligent agents, when claiming that systems consisting of humans, too, implement similar emergent functionalities, one has to motivate why the simple model structures still are applicable. For example, what are the "mental degrees of freedom"? As shown in chapter 7, neuronal elasticity in the realm of signals can easily be motivated, but how about the higher level, the visible level of mental functions? Indeed, at least there are some qualitative intuitions that are supported: In a new situation the behavioral spectrum is wider for a novice than for an expert. Through cumulating life experience the "mental stiffness" increases as the process of automatization is manifested in all types of behaviors. Because of the difficulty of quantifying abstract phenomena, nothing very concrete can be said here — however, as studied in chapter 5, the variables in one's subjective world become the measures that characterize the objective world, too.

How about the learning strategy Hebbian-style — is that obeyed by humans? There are two opposite mechanisms that are needed: Further adaptation towards the resources in the case of intense activation, when doing the "right things", and reallocation of efforts in the case of deprivation, when doing the "wrong" ones. And, indeed, it can be claimed that there exist the two classes of basic low-level mechanisms that seem to be wired in human brains — and, at least to some extent, also in less sophisticated animals:

1. **Motivation strategies.** When one invests effort in reaching some resources, successfully managing in doing that, this behavioral pattern is typically strengthened. In other words: When one's activity $\bar{x}_i$ is rewarded implicitly in terms of resources in $u$, one's behavioral profile is adapted towards such practice, so that there will be more activity in that direction. Clearly, this is very well in line with the assumed cybernetic learning strategy. For humans, the resources and rewards need not be concrete — the "resources" in $u$ can be different kinds of *possibilities* available in the environment, and the reward can also be provided in terms of *encouragement* by some external critic. On the other hand, similar (but less abstract) learning behaviors have been observed also in animals that can modify their forage habits according to the available prey; in lower life forms, the conditioned reflexes are a manifestation of the same non-genetic accommodation processes.

2. **Compensation strategies.** What happens, on the other hand, if an agent never succeeds in its strivings, always being turned down? Among lower-level organisms, when the competition concerns food and other physical resources, this typically results in the organism gradually fading away — however, for intelligent agents the results need not be so acute: When the resources are interpreted as possibilities, there exist other options. The psychological concept *compensation* means the mental reaction against disappointments (among other protective mechanisms), where one claims that "it was not what I wanted really". In a way, it is only self-deception — but it is very real in one's subjective world. The "local reality" will be re-evaluated, the unattainable resources are understated; in technical terms, this means that one's weightings of the variables are redefined.

> This may change one's orientations altogether: Hopefully one can finally exploit and further develop one's personal capacities, when the domain of one's special talent is found.

When studying both of the above mental processes, and the corresponding behavioral adaptations, the creativity of a human seems to be endless. There always exist new ways to see the world and its possibilities, and new ways to better manage are invented. When a human implements system adaptations, wider views and understanding is available: When there exist various separate cybernetic systems coexisting in the same mind, cross-fertilization of ideas becomes possible.

Animals can actively not only change the weightings of the variables, but they can also change the contents of them — moving to another environment, for example — but human's flexible mind makes it possible to change not only the values but the variables themselves.

Introducing new variables means that the structure of the system changes. Structural changes can be implemented in a human mind in a very efficient way. Intelligence makes it possible for an agent to escape outside the existing constraints of the prevailing ways of seeing the world. However, free will is a fallacy — with a twist: Even though quite original behaviors are possible in principle, not obeying the basic cybernetic principles is not seen as personality — such destructive behavior would generally be regarded plain insanity.

### 4.2.2 Intelligent organizations

When seeing in the wider perspective, the above selfish strategies result in merciless competition. In the social animals, there seem to exist mechanisms to easier find the sustainable society-level dynamic balances: Some primates share a simple hard-wired social strategy that could be called *monkeying,* perhaps the simplest form of co-operation. It is typical also for humans to mimic behaviors and follow the leaders, making it easier for organization in low-level societies to emerge. But humans are not bound to the hard-wired behavioral patterns: Cultural evolution has bypassed the biological one.

There are some functionalities that are necessary for a cybernetic agent: One needs *sensing, inference,* and *memory,* or, in concrete terms, measurement and analysis of signals, recognition of correlation structures, and storage of these structures. If the agents have more capacity, it is possible, for example, to implement different kinds of optimization strategies. Whereas the simplest agent only tries to survive, not taking other agents into account, blindly exploiting the resources it can see in its extremely narrow local world, a slightly more sophisticated agent can see its environment in a wider perspective: It can see the actions of its neighbors, and it can actively start avoiding competition. A more intelligent agent not only tries to go for resources according to (3.13), but it also escapes neighbors, predicting the interactions and taking the feedbacks into account beforehand, changing the "Hebbian learning strategy" into "Hebbian/anti-Hebbian strategy" [92]. Such higher-level strategies make it possible to reach emergence of higher-level structures (principal subspaces, etc.) also in rigid, non-flexible environments, where feedbacks will not become implemented through the environment (this is the case, for example, if the population exploiting the environment is negligible as compared to the amount of resources). And if an agent can see still wider horizons, it is possible to optimize even further, reaching towards cybernetic optimization, balancing among a network of neighbors; such balancing becomes easier if there is cooperation, and if the agents can somehow negotiate.

Communication, or "negotiation" among agents in its simplest form is mere signal transfer: It is not necessarily a purposeful act, as distribution of the physical chemical levels can be seen as transmission of variable values as well. In lower animals and especially in insects, chemicals play a central role in communication not only within a single organism but also among them. In the world of smells and scents, low concentrations of thousands of chemicals can be detected, each of them augmenting the vector of available cybernetic variables, and it is pheromone transfer among the signal carriers that guides the construction of ant hills, for example. In higher animals and especially among humans, on the other hand, more complex coding of messages takes place. It is the quality and extent of communication among humans that determines the limits of *learning organizations* as discussed in [71] — issues concerning "information bandwidth" are discussed in chapter 5. Because the principles are (assumedly) identical on different layers of cybernetic systems, the functions of a single human can be extended in an organization of several humans assuming that information transfer can be provided in a seamless way. The possibilities of the organization to construct networked intelligence is dependent of the agents' abilities to understand each other; in this sense, perhaps it is the EQ, or *emotional intelligence quotient,* that determines the capacity of the higher-level intelligence. It is all about information transfer — systems can become one if the communication among them is tight enough.

But if an agent is (too) intelligent, it probably uses its wits to choose itself how to utilize the information. To avoid anarchy and to reach evolutionary advantage on the society level, not whatever game theoretic optimization in the intelligent agents can be tolerated as a general rule, however. To reach emergence of higher-level patterns in the global system, it is beneficial if the agents share some common code. There are no genetic chains, but there are cultural ones. After all, the agents need to be *humble,* obeying some *categorical imperatives* that somehow persuade or press the agents to think about the common good. It is not a coincidence that in all prospering human cultures there have been some religion dictating the roles for the individuals. However, the moral codes can be implemented not only through religion, but also through philosophies or through secular legislation — somehow expressing the Kantian idea "only act in such a way that wouldn't ruin the system if *everybody* acted that way". And, today, the modern imperatives guiding towards the "economical optimum" are implemented in terms of *fashions,* etc. Culture and social codes help in finding one's niche without wasting ones energy in vain, kicking against the pricks. There is a niche for only one clown in the classroom.

There are humans with varying properties. In an intelligent organization this is taken into account, and the tasks and workloads are organized according to individual abilities. A team needs its organizers, "mood makers", etc.; the traditional line production style optimization is not cybernetically robust. As the humans learn their jobs still better, adapting in their environments, counteracting the local tensions, finally finding their niches, the operation of the organization becomes streamlined. In the cybernetic framework the evolution theory can be extended to human cultures without having to employ the cruel ideas of "social Darwinism".

One can also draw conclusions concerning wider organizations. The "Adam Smith Type" capitalist economy is efficient, explicitly implementing the survival of the fittest, but a designed welfare state based on global-level optimization directly implementing the global equilibrium can be even *more efficient* — *assuming* that the underlying model of the society is correct. The laws, etc., should be determined based on correct predictions of the system dynamics and inertia. The less one can afford experimenting and iteration, the more accurately one should capture the balance already in design. Intelligent, more cultivated strategies make it possible to avoid needless competition — struggling for life, or *suffering* in general, as studied in the Eastern philosophies, and also by Western philosophers like Arthur Schopenhauer.

To truly understand the universality of cybernetic thinking, one can extend the studies from *autocybernetic* to *allocybernetic* systems: This far, the actors implementing the functionalities have been themselves part of the system; now, however, it is assumed that the actors operate in *another phenosphere.* Still, after the variables are evaluated and the adaptation is carried out, it is the general cybernetic principles that determine the domain area structure regardless of the intentions of the actor.

### 4.2.3 Constructivistic systems

The extended intelligence in agents can be exploited in different ways. It is all the capabilities that can be enhanced: New variables can be made available, more storage can be allocated, and structures of correlation can be defined in new ways; "creativity" is the key to clever combinations of new capacities. There can exist various overlapping optimization processes with different sets of variables taking place simultaneously in one agent, opening up a wealth of cybernetic, fractally overlapping systems. A human agent with his/her magnificent mental capacities can operate on phenospheres that this agent is not physically part of. There exists no exact borderline between autocybernetic and allocybernetic systems — the larger the system is, the more the system follows its own dynamics, and the human can only look aside; or, indeed, the human changes to a mere signal carrier.

When the agents are human beings, perhaps the most characteristic allocybernetic systems are located in *infosphere* or *ideasphere.* The "idea atoms" are called *memes,* and they are the "genes of the infosphere", being the building blocks to be appropriately combined [20]. The term "meme", referring to some concrete idea, is not always quite appropriate; typically, needs and desires are not necessarily ever explicated. The human mind supplies for the platform for the memes to operate: Humans collectively host the memetic systems, acting as the signal carriers, and providing the machinery for emergy processing. Even though constructivistic systems are explicitly designed by humans, after the memetic platform has been consistently instantiated, so that reasonable balances among "memetic tensions" can be found, it will start following its own dynamics, the memes trying to prosper among competitors, assumedly obeying the cybernetic principles. The final success criterion is the match with the environment, memes together explaining the observation patterns. To constitute a cybernetic system, there needs to emerge a dynamic balance, meaning that there needs to exist a competition of counteracting memes finding equilibrium. The human's contribution to the memetic dynamics is that he/she defines the environment for the memes, coupling the variables to the real world, choosing the relevant observations (variables) and interpretations for them, also supplying for their evaluation (weighting of the variables). The emerging structures depend on how the world is seen — how the abstract and non-concrete phenomena can be quantified, is further studied in Sec. 4.3.

Emergent structures in infosphere are, for example, theories or paradigms (when talking about science), or "isms" (in politics). Study some examples of such complex domains — there may be some cybernetic intuitions available.

### Society and politics

In a social system, and specially in politics, the "variables" are those issues, resources, possibilities, and needs, that are being discussed and debated. The intuitive common goal is to reach a systemic balance state where there are no more unjust evils. Of course, visions of the utopia differ as the weighting of different issues differs among citizens in a pluralistic society. The views of ideal society, or the agenda of aspirations, becomes manifested in the programs of parties and profiles of candidates in elections. How to measure and quantify the state of the complex social system, then? In the political arena, the contradicting aspirations are made explicitly quantifiable through a kind of Analytic Hierarchy Process [68], where alternatives are given to voters to choose from: Different opinions become quantified in elections. Popularities of parties (number of votes in $\bar{x}$) can be assumed to reflect the vector of needs $\bar{u}$ in the society — and, in the democratic system, this popularity is reflected in the capacity of implementing the party visions. In a way, the role of candidates (and parties) is to act as *probes* to identify the infinite complexity of the society (see Sec. 4.3).

Why democracy seems to prosper even though it is less efficient than a (Platonian) dictatorship, why is democracy typically restored even after turmoil periods? Assuming that there is complete information available in the society, democracy represents the *most cybernetic political system,* giving the maximum information from the bottom level to the top, thus keeping such a system maximally up-to-date. Parties determine profiles of opinions; party popularity (number of votes $\bar{x}_i$ corresponding to the party profile $\phi_i$) reflects specific needs $\bar{u}_j$ in the society, and this voter support is reflected in possibilities of implementing party visions. When representatives are selected, not all decisions need to be brought to the ground level. Is the current system the best possible, then?

> In the era of enhanced information technologies, more sophisticated voting practices could be employed, for example. The current voting scheme is too coarse to reveal the nuances in opinions. Why not allow a *spectrum* of votes, so that votes could be distributed among candidates, the total weight of one's votes still equaling 1? Today,

> each party has to be the voter's only choice, making it necessary to become a "general-purpose party". In a long run, this results in a democracy that cannot respond to changes: When all parties become identical, no structure among the parties emerges any more. In principle, in a fully cybernetic society, the parties should span the principal subspace of existing aspirations; now, when only the mainstream averages are followed, the developments in the society become more like random search process. What is more, different kinds of thresholds, etc., jeopardize the linearity of this model of the society.

In any case, each tension (or aspiration) has to be finally compensated by counter-tensions — otherwise, the system becomes pressed endlessly, and the system collapses.

Seeing the politics as a cybernetic system perhaps makes it possible to understand and react to the pathological developments. For example, today it is no more possible to restrict the "variables" to those issues that one would like. In the postmodern society there seem to exist no real acute problems, and criteria are in a process of change: Politics is becoming entertainment, debates become "true television", where substance is substituted with appearance. Or, putting it more philosophically: The cultural patterns emerging from the human values and aspirations reflect the *Weltgeist* in the spirit of Hegel.

**Scientific communities**

Similarly, in scientific research there are complex domains to be explained: Together the theories span the space of observations so that a reasonable balance between models and reality is reached. In principle, the most important criterion for a good theory is the match with reality — but the reality can be seen in different ways, or the relevance of different phenomena can be assessed in different ways. In natural sciences, the external world really exists and there are concrete measurements available, but also there, it is the interpretations and internal dynamics of the scientific community that plays a central role. In the postmodern era of "ironic sciences" (as discussed in [40]), the similarities among branches of scientific work are becoming more and more evident, and *consilience* seems appropriate [90].

The central challenge in all scientific work is to define the variables and their weightings: What is relevant, and how important it is. These issues are settled when the framework is fixed: This framework can be identified with the *paradigm* in the Kuhnian structure of sciences [49]. Within the paradigm, there are theories, or scientific memes, competing for popularity, individual researchers just acting as information carriers. Such paradigms are rather stable attractors — as long as they can sufficiently address the real-life challenges. But after new sets of theories clearly outperforms the previous ones, the paradigm shift can be abrupt.

Determining what is "good science" is a specially challenging task. By definition, science should tackle with something that is unknown and unstructured, so that no *a priori* weighting can be reasonably defined. Instead of the subtle contextual criteria, better quantifiable bureaucratic guidance is becoming more and more dominant: It is easy to define numeric measures — like number of publications and amount of publicity, etc. Todays answer, common to all branches of scientific work, is to trivialize the problems, inflating the strictly scientific criteria. Also the criteria based on peer-reviews are problematic: When goodness of research is defined in terms of match with the scientific community, a scientific paradigm becomes a self-sustained entity. Science is what scientists do — as studied below, reality is molded by the actors — or, indeed, reality is *created* by them.

Yet, however long the wrong tracks are, the Darwinian dynamics in science is extremely efficient and cybernetic. When some scientific branch is most active, new interesting facts being detected, it also is most adaptable: There are bright minds and financing available, making adaptation fastest in the directions of maximum benefit. On the other hand, nobody feels pity of the losing theories, such researchers having to search for new directions, resulting in structural rearrangements in that field. This all is perfectly in line with the Hebbian-type learning. As contrasted with economic environments, there is a clear difference: In science the idea is to "change the behaviors when the times are good", but in companies the principle is to "not fix if it still works" — adaptation taking place only in bad times!

### Case: Stock markets

As an example, study a better quantifiable domain field that is explicitly constructed but whose dynamics is still beyond control, and even beyond comprehension: *Stock market* was originally created for balancing the imbalances in economics, but today it seems to have escaped the controls, following its own chaotic dynamics. It seems that such a domain field offers a possibility of more or less immediate application of new thinking; it has become an independent cybernetic entity itself, pursuing balance but being vulnerable to catastrophes (see chapter 5). Contrary to the claims, the behaviors in the market cannot be reduced to the economical fundaments. The stock market is a prototypical example of a yielding elastic systems: As the demand rises, the price goes up until the balance is found. This balancing is very fast, and also adaptation of the system is fast, as money is transferred in principle without delay and the model structures exist only in the form of expertise in the analysts' brains. Stock market truly is an extreme example of maximum exploitation of information on the edge of understanding (chapter 5).

The underlying dependencies among the exchange rates are not known — but they need not be known. Indeed, because of the fast information exploitation, the stock market can be seen as being in a dynamic equilibrium where opposite drifts balance each other; what is more, as the agents all the time try to maximize their profits, balances are being tested all the time, and there is maximum regeneration of information. The balance indeed changes to generation of excitation, so that there is inherent drive towards the edge of chaos.

In principle, there is the underlying real world that determines the market prices — however, the dynamics is detached from the underlying realm, behaviors being based on internal tensions. It is like it is in *cognitive systems* — the

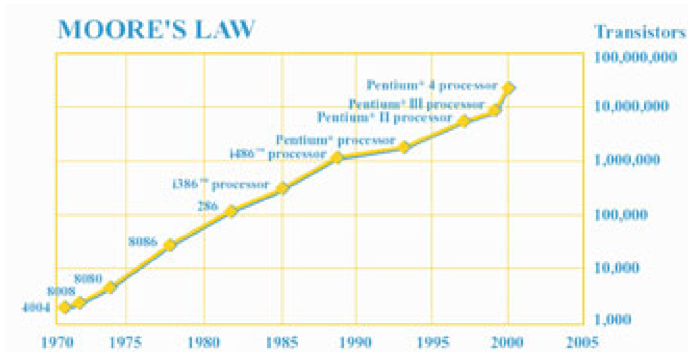


Figure 4.5: Evolutionary behavior is typically exponential

"grounding of semantics" can be left floating, as long as the "semantic atoms" are included in the data (see chapter 7). As compared to memetic systems, all relevant variables are visible in numeric form — they have the dimension of *money*. Assuming that the market reactions are consistent functions of the system state, including enough statistical features characterizing this state, self-contained balances can be defined. If the market has had time to converge to a higher-level balance, the neocybernetic principles can be applied for capturing the system state as a whole.

In today's world, the best proof of a new theory is the amount of money that can be earned when using it. Thus, the stock market offers a nice test bench — let us study a scenario to perhaps be tested in practice. Neocybernetic guidelines make the abstract modeling problem concrete and compact. First, to construct a model, statistical analysis that is based on the observation data only is sufficient; no complicated rule structures, etc., are needed to capture the balances. As discussed in 7.1.2, to capture the "cybernetic semantics", one also has to include the trends or derivatives of the variables among data in addition to the variables themselves. There are also guidelines for carrying out the preprocessing of the data: As explained in 4.3.3, the variables are scaled by their mean values, and only thereafter the mean is eliminated. This way, the cybernetically efficient variation is appropriately weighted; because the variables are always positive, such scaling is possible.

The neocybernetic model structure is then based on extraction of statistical dependencies among data in terms of sparse features (as explained in chapter 6). The algorithm assumedly reveals the market state in the framework of the neocybernetic market structure, showing the internal tensions within the market, making it possible to carry out predictions of the plausible developments.

### 4.2.4 Boosted evolution

As the properties of constructivistic systems are difficult to capture, changes in them are still more difficult to model. However, when constructing models for complex systems, and when trying to predict the future, such evolution processes are perhaps the most fundamental processes of all.

In the allocybernetic systems, individual humans implement the adaptation. Constructivistic systems can be designed and optimized explicitly, and when the agents are such intelligent, it should be easy to see where to go? However, as studied in the previous chapter (also see Section 4.3), the environment is unknown, and it changes as the system changes. The models need to be based on observations rather than on theories, and the adaptation process necessarily becomes iterative. There has to be enough time to observe the changing behaviors in the changing world. However complicated the environment is, it needs to be in balance with the system, and there exist some intuitions that are available here.

Humans are the agents that determine the variables and implement the enhancements — and the developments are caused by individual geniuses, making the evolution a very stochastic process. However, as seen from distance, details vanish: To penetrate the whole population, to become a truly revolutionizing change in thinking patterns in the large, any innovation needs to be accompanied by a large number of related breakthroughs in separate minds.

The memetic systems, too, seem to have their own internal dynamics. In allo-cybernetic systems, the agents do not experience physical hunger or other acute motivations, and different kinds of driving forces are needed to look for new frontiers. This mental imperative can be interpreted as "engineering spirit", curiosity that is boosted by greediness, resulting in objectives like *citius – altius – fortius*. These human aspirations, as seen from outside, become manifested as the systems "trying" to become somehow better: Faster, cheaper, more accurate, etc. Typically, the system goal is hypothetical, never reached — zero cost, zero delay, etc. — so that in this respect, the final balance is never reached, systems evolving forever. Momentarily, the cybernetic balance is determined by technical / economical / social possibilities and constraints.

In all its complexity, evolutionary processes can be abstracted in terms of the coupling coefficients $q_i$. Stiffness in the systems grows, coupling becoming stronger, $q_i$ growing towards infinity. Why this happens — according to (3.13), the emergy transfer between $u$ and $\bar{x}$ assumedly becomes boosted then, impedances getting lower, but another point of view is studied in chapter 10.

Very different phenomena affect the adaptation of the coupling coefficients, and this adaptation becomes a very random process. Parameters $q_i$ are determined in other phenospheres, and there are many underlying variables and processes contributing, the cumulative outlook of behaviors becoming more or less continuous. In technical systems, when facing "designed evolution", developments are based on explicit investment calculations, economical pressures implementing balancing tensions, and smoothness and consistency in developments become explicitly underlined. Rather than studying $q_i$, it is easier to concentrate on $1/q_i$, typically having the unit of "price", "size", or "slowness" of a device. The final balance would be in zero, and as the process towards the balance can again be assumed to be a "next-level" generalized diffusion process, there will be exponential decay (see Fig. 4.5 for a manifestation of this "Moore's law"). Formally, this decay can be modeled as

$$\frac{d\ (1/q_i)}{\gamma' dT} = \frac{1}{q_i}, \tag{4.1}$$

where $T$ yet slower time scale beyond $t$. No matter what is the prevailing level of $q_i$, the subsequent enhancements are relative to that level.

### 4.2.5 Hegelian megatrends

When trying to characterize extremely large systems, and when connection to concrete data is lost, the discussions necessarily become vague. Here, it is best to trust intuitions of established visionaries. The best explication of cybernetic ideas since Heraclitus (and equally obscure!) is given by Georg Wilhelm Friedrich Hegel (1770–1831). A more readable presentation of the "passions" of memetic spirits is given, for example, in [77].

Hegel was very influential in his time; it is essentially his ideas that are reflected, for example, in the writings of Johan Wilhelm Snellman, the inspirer of the Finnish national spirit. According to Hegel, history of mankind in general, and that of individual societies in special, is an evolutionary process[1]. In a way, Hegel can be seen as one of the first system theoreticians: Only the whole is consistent and a real thing, all partial explanations being illusory and deficient. Many of his thoughts can be interpreted in terms of cybernetic concepts — essentially, Hegel is speaking of *very complex agent-based emergent systems.* In the Heraclitus spirit, the essence is not *being* but *becoming.*

Specially, in a constructivistic system composed of human ideas, thoughts become diluted in the whole; true and false become intertwined, together constituting a consistent whole. The concept of "true" here contains logic and ethic considerations. What is more, everything is in change: The system becomes more and more complete in both logical and ethical sense. The results of human endeavors, or nation-states, are manifestations of the history, being — again applying modern terminology — relevant attractors of dynamical processes. Also Hegel's definition of what reality is like is very modern, emphasizing relevance: What is reasonable is real, and what is real must be reasonable.

Hegel emphasizes systems over individuals. For example, for him *freedom* is a contradictory concept: For individuals this is only freedom to follow laws (or some categorical imperatives), to make it possible for the larger system to become stronger and to develop further. The nation-state is not for its citizens, the citizens are for the state; it is a "person" of its own, deserving its existence over individuals.

The key concept in Hegelian philosophy is *dialectics,* or the idea of *theses* and *antitheses* (later employed by Thomas Kuhn). It is one dominating thesis in the society that finally finds an opposing antithesis, and together they form a synthesis. Contradictions do not collapse the Hegelian system; such seemingly illogical assumptions were attacked against by logicians. However, in the cybernetic setting, this all is quite consistent: The opposing theses determine tensions that together determine the dynamic balance that is necessary for the higher-level categories to emerge. The idea of dialectics was further elaborated on by Karl Marx and contemporaries; this is an example of how it is dangerous to apply rational reasoning without empiristic support — extrapolations easily result in irrational conclusions.

According to Hegel, all that fundamentally exists is really *mind* or some kind of *absolute idea.* The absolute idea is a consistent thought that "thinks of itself" — this is a poetic way of expressing a model being in statistical balance with

[1] Strangely enough Hegel did not yet foresee Darwin's work, never extending his studies to the biological realms

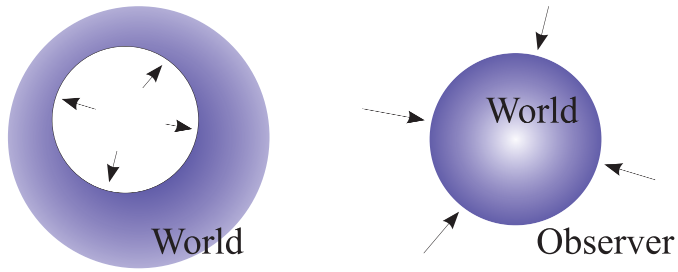


Figure 4.6: The traditional view of looking at complexity, on the left, and the cybernetic view, on the right. The system implements a mirror (or a lens?) that makes it possible project the infinite unstructured complexity onto a compact set of variables

the environment (see next chapters). The essence of this “Geist” or Idee” is similarly obscure as the Heraclitus’ Logos is:

> *Der Begriff der Idee, dem die Idee als solche der Gegenstand, dem das Objekt sie ist.*

## 4.3 Quantification of phenomena

In the earlier chapters it was concentrations and other quantities that were easily coded in real-valued numbers. In complex environments, however, the variables generally cannot be quantified in such a straightforward way, and analyses have to be left on a more or less heuristic level. This applies specially to memetic systems — but also in economical systems, for example, even though it is money that makes values compatible, problems emerge if phenomena cannot be “moneyfied”. Today’s economic tradition seems to ignore everything that cannot be measured — but one should not deliberately limit one’s analyses to approaches that already have been seen to be deficient when describing the complexity of the real world — otherwise, only a hollow formal system remains. Cybernetic considerations seem to offer new points of view here.

### 4.3.1 Mirrors of environments

As compared to traditional physical quantities, cybernetic variables are diffuse: They cannot be detected and quantified in an explicit way from “outside”. They are fragile: Just as other emergent phenomena, any formalization of them misses their actual essence. They do not exist as independent entities, they cannot be isolated from their environments, as they are only relevant in interaction. In the cybernetic spirit, one can say that they are defined in terms of balances — employing the mechanical analogue, they can be defined in terms of the ratio between a “force” and the resulting “deformation”.

To appropriately maintain the balance determining the observation, it is necessary to have the corresponding system connected in the environment. This means that the system disturbing the environment constitutes a “probe” that changes the potential tensions into actual observables. The infinite-dimensional complexity is projected onto a distinct set of variables. The results reflect not only the surrounding world but also the agents and their ways of seeing the world. Extending the Protagoras' statement, it is not only so that "man is the measure of all things", but it is *all cybernetic systems that constitute measures of their environments.* Remember the "Barnum effect": When there are enough variables, a consistent model can be constructed from practically any starting points (compare to the popularity of horoscopes, numerology, etc.).

This close coupling of the system and the environment means that the world also changes: Again employing the steel plate metaphor, affecting the deformability in one location affects the whole plate. When the system is completely cybernetic, there is constant stiffness in the observation points, so that the variation is pushed onto a constant level in *baru* — but simultaneously the system casts the variation onto another set of variables $\bar{x}$. In this sense, the environmental variation is mirrored onto the system (see Fig. 4.6). There can exist excess variation in the environment, but it remains hidden if there are no measurements. The world as it is seen is maximally supported, or spanned by observations; world is realized only after the measurement is carried out (compare to the "Schrödinger's cat"). Indeed, it is not only in the world of the simplest elementary particles where the measurement disturbs the system being studied — also in the other end of the continuum, when modeling extremely large systems, measurements alter the system being studied (or, more accurately, the measurement system alters the environment). In this sense, analysis of cybernetic variables is related to discussions concerning the general problems of *observer effect.*

Implementation of systems constitute the concrete "anchors" fixing the environment. Following Archimedes, one could say that "give me where to stand, and I will move the earth" — fix one point and the rest of the world will change to fit this constraint. As the world changes, the visible optimum state is dependent of the earlier decisions. The variability of evolutionary adaptation becomes easier to understand in this perspective: Because of the changing world, the optimum state is not predetermined after all (compare to Fig. 4.2). Whatever are the past developments, there are no dead ends, and further developments are based on the prevailing view of the world.

The extended capacities in intelligent agents make it possible to employ new variables, applying new interpretations. Variables in the memetic system are, for example, new concepts that change the ways how the world is structured. To find appropriate variables, intuitive understanding of the structure of the domain field is needed. The domain area expert typically recognizes the imbalance if there exists some, and innovations are introduced to compensate the tensions. In science, new theories are proposed — in economy, new products are proposed. A concrete example is needed here.

### 4.3.2 Cases of supply vs. demand

As an example of the "steel plate" analogue, study the *product market.* The market here is seen as the "product universe", unstructured entity, where the products constitute the contact points to customer needs, defining the set of

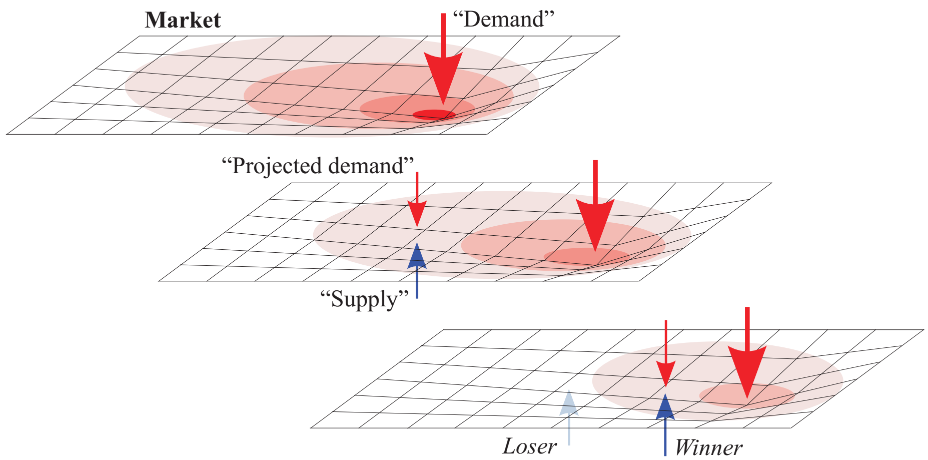


Figure 4.7: Exploiting the steel plate analogy (see Sec. 3.3.2). The unsatisfied demands (unobservable) are like forces that deform the balance market (here it is assumed that the force remains constant, so that the variance of this $u_j$ is simply the square $u_j^2$). When a product is introduced (middle), it compensates some of the deformation, so that in that location the residue deformation after adaptation assumedly is only $1/\sqrt{q_i}$, as shown in (3.36)). When a competing product that in all respects better matches the demand is brought to market (bottom), the earlier product, masked by the new one, soon fades away: The deformations in that location remain below the level $1/\sqrt{q_i}$, and this product becomes "sub-cybernetic" (this behavior is verified also by simulations). Increasing the value of local $q_i$ (lowering the price), or otherwise modifying the market (advertising the product, for example) can still help

quantifiable cybernetic variables. When this universe is presented as a concrete, visualizable entity, perhaps the simplification is not too radical (see Fig. 4.7).

The theories concerning the relationships between *supply* and *demand* are cornerstones of modern microeconomics [61]. There, the intuitions concerning elastic systems are clearly appropriate: For example, concepts like *price elasticity* are employed there. However, even though "demand" is a practical abstraction, it is difficult to quantify in general terms. It has been claimed that there cannot exist demand before there is supply — indeed, it is *Say's law* that puts it even stronger: "Act of producing aggregate output generates a sufficient amount of aggregate income to purchase all of the output produced". Now, the "forces" acting on the market are the potential demands, and the "deformations" are the actualized demands. It needs to be noted that, again, only balances are concentrated on, and it is assumed that in balance supply equals demand. In this sense, the vision of cybernetic economy is an idealized one.

In Fig. 4.7, it is shown how the abstract demand deforms the market. This demand is compensated by supply: A product is introduced — the properties of the product determine where it is located in the market. Some of the demand is projected onto this location, becoming a really measurable quantity. In the market domain, it is the products that are the probes quantifying the complex reality: The environment does "not exist" before there are the probes, so that the entrepreneurs restructure the world. In balance, it is the supply of the product that must equal its demand. If a more appropriate product is introduced, better matching the demand, the older product loses its support. It is the "stiffness" of the market that determines the properties of the equilibrium, and if a product is too "loose" as compared to the market stiffness, it is to finally vanish. Longer-range reformations of the steel plate as local changes take place can be interpreted so that the new products either complement or substitute other goods, changing their demand. If the demand is fixed, there can exist a monoculture after adaptation, but if there is variation — various "demand vectors" in different locations stochastically varying — there will be diversity in balance.

New products typically increase market stiffness, compensating still new locations of deformation, making the steel plate less compliant; this increase in stiffness is the natural route towards local evolutionary optimum. It is the products that implement this increase in stiffness, finally being distributed to compensate the external demands.

What is the physical interpretation of this stiffness, then? There are many factors that affect this coupling, but perhaps the most characteristic is *price,* or, actually, its inverse, so that the local $q_i$ is proportional to the inverse of the price of the corresponding product. It needs to be recognized that for any selection of price there exists a balance — but the market is deformed, demands being redistributed accordingly. The higher the price is, the lower $q$ becomes, and at some value this product drops out from into the subcybernetic region, finally fading away. If supply is well aligned with demand, and if there are no competing products, higher prices are tolerated.

The trivial goal that is always fulfilled for a cybernetic market is the local, product-wise balance of supply and demand, but the evolutionary goals on the local and global levels are different: Whereas an individual product provider tries to maximize the profit, maximizing the unit price or $1/q_i$, at the system level it turns out that the market becomes stiffer, $q_i$ being maximized and price *minimized,* so that demand is better compensated by supply. And in an environment of independent distributed providers, if there is no monopoly, it is this system-level criterion that outweighs the local criteria, the individuals having to adjust themselves. How long the global-level evolution has proceeded is dependent of how mature the market section is, and how thoroughly the demand has been penetrated into.

Finding the "edge of the market surface" is of extreme importance for an individual product provider. This edge between the cybernetic and sub-cybernetic region can (in principle) be identified by experiments: Increase the price until (in balance) the net income does no more increase. It is the "effective actors" that determine the market structure, and if price changes do not cause changes in demand, the product is disconnected from the market surface. Here it is assumed that the product provider can respond to the whole balance demand; if there exist some hard limitations in production, for example, elasticity in this part of the market is lost. In the ideal case, the working economy becomes an image of the abstract market: Products are appropriately located, and they efficiently reflect the demands.

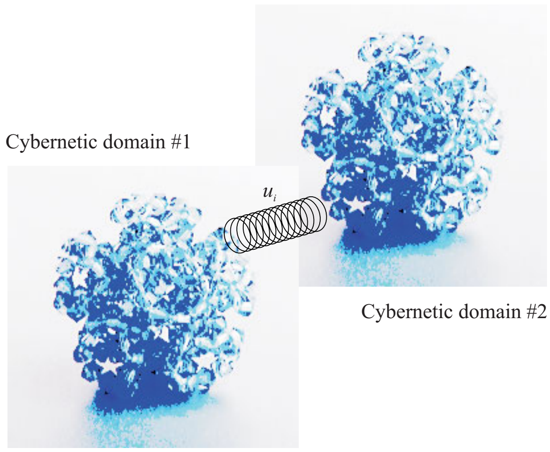


Figure 4.8: Abstract domains constituting cybernetic systems of their own are coupled by cybernetic variables

Where do the abstract demands originate from? Normally, such issues are not studied very much — this domain of the obscure human decision-making has traditionally been seen as something unmodelable. However, in the cybernetic framework, where abstract notions become quantifiable, it may be possible to go further. The human decision-making process assumedly is another cybernetic system where different kinds of tensions — desires — coexist, and this mental world can similarly be mapped in terms of a distinct number of cybernetic variables. The connection between the two cybernetic systems is instantiated by those cybernetic variables $u_i$ that are common to both domains. And, in balance, it has to be so that the impedances in terms of $q_i$ match in both systems: It is $1/q_i$ that determines the variation of the variable, and this variation is the same in both systems (see Fig. 4.8).

The above discussions can be generalized: One could say that *complex systems become observer-oriented systems,* the roles of "subject" and "object" becoming blurred. Indeed, they share the paradoxical properties of quantum mechanical systems, being like "Schrödinger's cats". In quantum mechanics, measurement makes the wave function collapse, revealing the single outcome out from the "cloud" of probabilities through the process of renormalization. Essentially the same intuition applies to the macroscopic as it applies to the microscopic: As studied above, the potential becomes actual through the process of becoming measured. In the extremely small scale, one disturbs the system being studied by accident, but in the extremely large scale, one has to disturb the system to make the measurements representative. The observer can only acquire relevant information about the system through becoming part of the system itself.

### 4.3.3 Towards different views of data

Two different, mutually incompatible approaches to seeing data have been studied this far: In this chapter, when studying populations, the models were *strictly additive* and globally linear, whereas in chapter 1, the connections among variables were *multiplicative* (models becoming locally linear after taking logarithms). Is there any possibility of again reaching homogeneity, so that it would be just one cybernetic model structure?

There are two levels of studying cybernetic systems: First, there is the *agent level,* being characterized by the individuals, and then there is the *population level,* where the effects of individuals cumulate. It is the individuals that are the actual actors, whereas behaviors on the population level are emergent. The appropriate way of seeing the environment changes when going from individuals to populations. The large number of individuals do not see the big picture, and it is not the actual level of variables that is of relevance. When trying to see the world from the viewpoint of an individual agent, it is first reasonable to divide the variable values (total activity of all agents) by the (average) number of the individuals — or, as the variable value is assumedly relative to the number of individuals, the variable should be scaled by its nominal value. As presented in the beginning of this chapter, the input variables, or the environment, can similarly be assumed to be consisted of other agent's activities, the same kind of prescaling should be extended to the input variables $u$, too.

But when looking the world from the point of view of an individual agent, additional modifications to data should be applied. As presented in the next chapter, it is *information* that plays the central role in cybernetic systems. This information is related to *variation* that the system experiences. Again, there is a big difference between the population and the individual agents: From the point of view of the whole long-living population, it is reasonable to study global long-term variations, that is, the behaviors of $\bar{x}$, whereas when studying the short-lived individuals that only can see a fraction of the time range of the whole population, the relevant variations are coded in the signals $\delta x$, transients around the local nominal values $\bar{x}$. This way, the whole range of behaviors in the data $u$, fast and slow, are modeled separately, together covering all of the variation. For the signals there holds $x = \bar{x} + \delta x$ and $u = \bar{u} + \delta u$, and for the accumulation of information, or "system memory" there holds

$$\mathrm{E}\{xu^T\} = \mathrm{E}\{\bar{x}\bar{u}^T\} + \mathrm{E}\{\delta x \delta u^T\}, \tag{4.2}$$

if $\mathrm{E}\{\delta x\} = 0$ and $\mathrm{E}\{\delta u\} = 0$. It turns out that this agent perspective — normalization by the nominal value and subtraction of the nominal value — is exactly the variable preprocessing that was proposed in chapter 1. Further, to make the models of the two levels compatible, also in the case of long-term modeling of populations, or when modeling the nominal values $barx$ and $\bar{u}$, it is reasonable to apply the same scaling: *Variables are to be divided by their mean values.*

It needs to be noted that this kind of scaling is *not typical* in practical data preprocessing — for example, this approach collapses for signals that have zero mean. However, such scaling can be done at least if the variables are strictly positive — as is the case with typical cybernetic variables.

When applying computational techniques for modeling data, determining the scaling of measurements is normally difficult, and some rules of thumb are normally applied: For example, the data is mean-centered and normalized to constant variance. The problem here is that when the modeling is based on (co)variations — as is the case when implementing PCA-like models, within or outside a cybernetic system — the scaling of variables is of huge importance, and formal variance equalization, even though being mathematically efficient, is not necessarily physically motivated. When the data dimension is high, these difficulties only become more acute. Now it seems that there is a more practical way of determining the scaling for cybernetic systems.

It seems that the behaviors and adaptations in cybernetic systems are dictated by the observations extracted from the environment. The key functionality in biological data processing seems to be redundancy elimination. When one now (assumedly) knows the principles of biological data processing, why could these data processing principles not be emulated, implemented outside the biological system, using computational approaches, to have a "cybernetic view" of the environment? When measuring phenomena, one uses the SI units, or some other technical standards — but such units do not necessarily have anything to do with the "natural" units, how the natural system sees the data. The measurements should become compatible if one applies special normalization for data: The measured values are to be divided by the nominal values. But one can extend these analyses of how data is seen.

Following the discussions in chapter 3, it seems that automatic data normalization is carried out for signals in cybernetic systems. There exist two extreme cases:

1. One could speak of "pre-cybernetic" data, if the measurements $u$ are acquired from an environment where the feedbacks not yet have essentially modified the environment. Then it is the scaling of the data in the form $u = M u_{\mathrm{orig}}$, where $M = \mathrm{E}\{\bar{u}\bar{u}^T\}^{1/2}$, or $M = \mathrm{E}\{\Delta u \Delta u^T\}^{1/2}$, that is appropriate.

2. Then, one could speak of "post-cybernetic" data, if the environment $\bar{u}$ has been changed because of feedbacks in the way defined in chapter 3. Then (if $q_i$ are assumed identical for different $i$) it is the scaling of the data in the form $M = \mathrm{E}\{\bar{u}\bar{u}^T\}^{-1/2}$, or $M = \mathrm{E}\{\Delta u \Delta u^T\}^{-1/2}$, that is appropriate to reach the "cybernetic" view of data.

In the former case, it is essentially the framework of principal component analysis (PCA) or principal subspace analysis (PSA) modeling of data that applies. However, in the latter case, it seems that *all variation-based information is ripped off the data,* and PCA-based methods collapse if only such "cybernetized" data is available. Eliminating the covariance structure means *whitening* of the data, and there is a connection to *independent component analysis (ICA)* or *independent subspace analysis (ISA)* here. In a post-cybernetic environment, where covariance structure has been ripped off it is the higher-order statistical properties only that remain available in the data; these properties can be made visible for PCA-type algorithms when special kind of nonlinearity is included in the structures (see *fourth-order blind identification (FOBI)* in [41]). Assumedly there is a continuum between the extremes, and the above analyses are clearly unsatisfactory.

As it turns out after closer inspection in chapter 6, where different views of seeing data are further elaborated on, rather than pure PCA or ICA, it is *sparse coding* that is being implemented by the cybernetic system. This coding is more robust against scaling, etc, and, what is more, such more complex codings can be reached without introducing extra nonlinearities.

Now, assume that all phenomena have been successfully quantified. It was *information* that turned out to be crucial for appropriately quantifying behaviors in cybernetic systems, and as it turns out, this concept is useful when abstracting away the details of the domain field. In the next chapter, the cybernetic domains are seen from yet another point of view, employing new and powerful concepts.