Chapter 11
The Slaving Principle, Circular Causality and the City

11.1 Order Parameters and the City

According to Synergetics, the interaction between the parts of a system gives rise to an OP that once emerged, enslaves the parts and so on in circular causality. As we’ve seen in the case studies described in Chap. 10 above (e.g. balconies, lofts…), the slaving principle and the associated circular causality took the form of a space-time diffusion process: they started at a certain space–time point, from which they were then diffused throughout the city and other cities (like the corona). What is specifically interesting is, that during this slaving/circular causality process, the OP itself is subject to local variations. For example, if we look at language (e.g. English) as an OP, its space-time diffusion entailed local variations: English–English, American E, Australia E. … S. African E. … Or if we look at urbanism as OP, its space-time diffusion entailed local variations: European cities (English, French, …), American cities, Chinese cities … they are all similar but with variations.

As noted in Chap. 2, the diffusion form the slaving and circular causality processes take in the dynamics of cities, is a consequence of the property of cities as complex hybrid systems. That is, that cities are composed of artifacts ( simple systems) and humans (complex systems). Now, artifacts of all kinds, including buildings, roads and whole cities, are subject to cultural evolution—a process that attracted intensive research (Creanza et al. 2017). Of specific relevance here is Cavalli-Sforza and Feldman (1981) study Cultural Transmission and Evolution: A Quantitative Approach. Commencing from a neo-Darwinian point of view, they propose that just as biological evolution is governed by genetic transmission, so cultural evolution is governed by cultural transmission. However, unlike biological transmission, which occurs between parent and child of successive generations only, in the cultural domain transmission takes place between parent and child of successive generations, between neighbors, and between neighbors of two successive generations. These are termed, respectively, vertical, horizontal and oblique transmissions. Similarly to “copying mistakes” (i.e. mutations) in genetic transmission, in culture a new cultural trait is
Fig. 11.1  *Left:* the spatial diffusion of agriculture from its core of origin in the middle east westward. The isolines represent time BP (before present). *Right:* the spatial diffusion of urbanism westward (mainly in the roman period) (After Portugali 2011)

born out of learning mistakes. Finally, as a genetic mutation becomes subject to environmental selection, so a newborn cultural mutation becomes subject to selection by the “cultural environment” that determines its fate to extinction or spatial diffusion. As an example, Cavalli-Sforza and Feldman reconstructed the spatial diffusion of agriculture Fig. 11.1 left. On Fig. 11.1 right we’ve added the spatial diffusion of urbanism.

Compared to biological evolution, cultural evolution (that is, the spatial diffusion of cultural traits) is an extremely fast process. There are, however, considerable time differences between such processes. Thus, the spatial diffusion of agriculture and urbanism (Fig. 11.1) are of the time-scale of thousands of years, whereas that of the new ICT (information-communication technologies) gadgets (or the corona) are at the time-scale of months. The speed of adoption depends, on the one hand, on the nature of the cultural trait (e.g. urbanism vs smart phone or coronavirus), while on the other, on the properties and spatial distribution of the potential adaptors. For example, in the case of agriculture and urbanism, the process implied that more and more socio-spatial-cultural communities had to undergo their specific cultural revolution—PT in the language of complexity: from hunting gathering to agriculture in the case of the Neolithic/Agricultural revolution; and from nomadic or sedentary agriculture to cities, in the case of the urban (PT) revolution. The outcome: the space-time diffusion of urban society, for instance, evolved as a sequence of smaller scale PTs, when each such community underwent its own specific urban revolution. For archaeological evidence of such a process see Portugali 2021; the Bedouin community in Israel is currently undergoing an urban revolution, from semi-nomadism to cities (see Lithwick et al. 2004).

To the above we should add, that the spatio-temporal diffusion of innovative cultural entities, evolves in line with our SIRNIA model described in Chap. 4 above: At its core is an interaction between two flows of information: externally represented information that comes from the environment and internally constructed information that comes from the person’s and/or social group’s memory. Furthermore, in the
information adaptation component of the SIRNIA process, each person and each society interprets, and thus adapts to, the innovative cultural trait in a somewhat different way that is affected by its past tradition and experience as constructed and represented in its memory. The result: each society interprets, adapts to, the new innovative trait in its own specific way which in the case of cities entails a variability of urban forms and cities: e.g. European, American, Chinese cities: they are all similar, all dominated by an urban OP, yet they also differ from each other and so on.

Finally it is important to add, that as noted in Chap. 2, the synergetics’ processes of slaving and circular causality are similar to what in social theory oriented urban studies is termed social, spatial and socio-spatial reproduction. Sources of influence here are, for example, Lefebvre’s (1974) *The Production of Space* and Giddens’ (1984) theory of structuration. Thus for Lefebvre, “biological reproduction and socio-economic production together constituted social reproduction, that is to say, the reproduction of society as it perpetuated itself generation after generation...”. Giddens refers to the interplay between ‘structure’ and ‘agency’ which in the context of cities implies the interplay between city structure and urban agents. “Structure”, he writes, “is both medium and outcome of reproduction of practices. Structure enters simultaneously into the constitution of the agent and social practices, and ‘exists’ in the generating moments of this constitution...”. The similarity to Synergetics’ view is apparent: by means of the reproductive processes of the slaving principle and circular causality, the city’s OP describes and prescribes the behavior of the urban agents. This parallelism is significant as it has the potential to bridge the gap between the two cultures of cities noted in Chap. 2 and open the way for CTC to participate in the discourse on the qualitative aspects and problematics of 21st century urbanism.

### 11.2 Behavioral Features May Cause an OP Hierarchy

While Sect. 11.1 provided the reader with a wide scope of OP diffusion processes over many time- and space-scales, here we turn to the special case of cities. A city is a complicated web of citizens with their various behavioral features and a variety of artifacts (cf. Chap. 2). In the context of our book we are interested in the way this web is coming into existence by self-structurization, i.e. without specific planning. Quite clearly, to characterize the fine-structure of this web an approach based on OPs referring only to gross features of a city such as total number of citizens, total income, productivity etc. is not sufficient. Rather we have to resort to more specific indicators/quantifiers. To bring out our basic idea we consider an explicit example that can be generalized—cum grano salis—to a number of other cases including large time- and space-scales.

Such an indicator/quantifier can be derived from the notion urban regulatory focus (URF) that we describe and study in some length in Chap. 13 below. As we show there, the notion of URF was originally suggested by Ross and Portugali (2018), then studied and elaborated in the context of synergetic cities by Haken and Portugali.
URF commences from Higgins’s (1997, 1998) regulatory focus theory (RFT), according to which individuals’ goal directed behavior is regulated by two distinct and independently operating, motivational systems—promotion and prevention. Higgins’s RFT further showed that each individual can be characterized by a specific mix of promotion-prevention tendencies termed chronic regulatory focus. Some people are thus promotion-oriented, while others, prevention oriented. Promotion oriented individuals are assertive, focus on winning and tend to take risks in order to achieve their goal, whereas prevention oriented individuals, in order to fulfill their aims and goals, prefer to avoid risks and to focus on not making mistakes. While Higgins’s RFT refers to individuals only, Faddegon et al. (2008) demonstrated empirically that one’s promotion-prevention configuration depends not only on one’s chronic regulatory focus, but also on the atmosphere of the group one belongs to. Based on these findings, they have suggested that promotion and prevention can characterize whole groups thus giving rise to a collective regulatory focus. Faddegon et al. study referred to small groups such as people in a workplace. Ross and Portugali have taken the issue to the urban domain, showing by means of a set of laboratory experiments, that cities differing in their atmosphere and ‘pace of life’ affect their citizens’ chronic RF. They have measured the effect of a city atmosphere on a person’s chronic RF by means of a response bias. In their model of urban dynamics, Haken and Portugali (ibid.) have termed the response bias variable ‘$b$’, and employed it as an OP in their urban simulation model.

Now we have all the ingredients together to formulate our general concept by means of this specific RF example. The conventional synergetics’ scheme

\[ \text{OP} \rightarrow \text{enslaved parts} \]

must be generalized to a hierarchy of OPs that is illustrated graphically in Fig. 11.2. As can be seen in the 3-layers hierarchy of Fig. 11.2, a specific feature (behavior) such as RF, quantified by a bias parameter $b$ plays the role of the top OP. The 2nd layer represents two groups of individuals, differing in their specific RF. One group, for
example, might refer to the citizens of a small city characterized by slow pace of life (low collective RF), while the other to the citizens of a large city that is characterized by fast pace of life (high collective RF).

According to the slaving principle, the behavior of the individuals/citizens of the 3rd layer is enslaved by the OPs of layer 2 that in turn are enslaved by the top OP. Now, according to the circular causality principle, the OP at the top level is fixed by the total behavior of the individuals (3rd layer). As we will detail below, the properties of the ensemble of citizens are represented by the distribution function $P(b)$ of its citizens with bias (features) $b$. The corresponding ensemble of citizens then determines the behavior of each individual.

Because of the interplay city (group)—individual, the behavior represented by $b$, may change in the course of time. This is represented by an OP equation for $b$ of the form

$$\frac{db}{dt} = -\frac{\partial V(b)}{\partial b} + F(t)$$

where $F(t)$ is a fluctuating force. We will derive $V(b)$ below for our RF-example. As it turns out, $V$ represents an attractor landscape with two valleys, that correspond to a low and high bias value. To each valley, we may attribute an OP according to Fig. 11.2 2nd layer.

According to URF, each specific behavioral pattern is connected with a specific city, i.e. also different location within a city (e.g. a quiet suburb vs. very active city center). This allows us to interpret and model the formation of these two cities as a diffusion process in analogy to the diffusion of a particle with position $b$ in a potential $V(b)$ under impact of random “kicks”. Mathematically, this process can also be dealt with by studying the time-evolution of the distribution function $P(b)$ (see below). Clearly, this model based on two links/valleys can be generalized to several links that allow the spatial spread of an OP over some distance.

After this summary of essential results of our following RF-approach/model, we discuss generalizations.

1. Employing RFT or URF is but one way to deal with human behavior. Quite clearly, there is a whole set of behavioral patterns/features. In a number of cases, these features are quantifiable. An example is provided by the walking speed of pedestrians (cf. Sect. 6.5). In other cases, we may define scales the way it is done in psychology. RF is just one example. Though the scales may be discrete, we may interpolate between steps so that we may attach a continuous variable to the “size” of the feature. This holds also for physical or mental skills. In all these cases we may derive or at least formulate OP equations (see also below).

If the features are completely or approximately independent of each other, the OPs are more or less independent of each other as well and we can deal with them separately. For each of them, $\xi$, there is a potential landscape $V(\xi)$. If it possesses only one valley, there is no need to introduce an OP-hierarchy and we may proceed
as elsewhere in our book. On the other hand, in case of several (≥2) valleys, we have to introduce the new layer.

To each valley we attach its OP that obeys an equation whose potential landscape consists of only one valley (see also below).

It must be emphasized that there is a whole class of behavioral patterns/attributes that don’t belong to the just discussed categories. Examples are credo, ideologies, languages, a.s.o.

Finally we mention that diffusion processes can take place at two different levels:

(a) The feature/property in question is transported physically, i.e., by migration of people
(b) By communication only

There are many phenomena that are based on the cooperation or competition of features (see Sect. 11.3).

11.3 Language and the City

11.3.1 OP and Circular Causality

As noted in Chap. 3, the language of a nation has all the typical properties of an OP. It describes a common features of the parts (individuals) of a system (nation/state/city) and it prescribes ( enslaves) the behavior of the parts: After birth a baby is subject to the language of his/her parents (“mother tongue”), learns it, and carries it further. The long-living entity language enslaves the behavior of the short-living parts (slaving principle based on time-scale separation). On the other hand, the existence of this very language is brought about by the collective actions of the individuals (circular causality). Note that the learning of this specific language is a prerequisite for the individual’s survival.

As further noted in Chap. 3, there are intimate links between languages and cities. In particular theories such as Hillier’s (2016) ‘space syntax’ and Alexander’s et al. (1977) ‘pattern language’, suggest that the morphology of a city is literally a language—a morphological language of cities. Influenced by Chomsky’s (1965) universal grammar, Alexander further suggested that at the core of all city languages there is a universal urban language—The Timeless Way of Building (Alexander 1979).

Whether one accepts Chomsky’s (and thus Alexander’s) view, or not (Tomasello 2003), the implication is that all that has been just said above about language, can be directly applied to cities and to a city’s OP. For example, we can rephrase the above sentence as follows: ‘After birth a baby is subject to the morphological language of his/her environment, learns it and carries it further’. The environment might be a city, a village or in some areas (e.g. Amazonia) still a jungle.

When a person learns a language, he or she learns (among other things) its syntax, semantics and pragmatics. As we’ve seen in Chap. 4, a city conveys quantitative
syntactic information that can be measured by means of SHI and two forms of qualitative information that we’ve termed SI and PI. To learn a city is therefore, to learn (among other things) the SHI, SI and PI it conveys. To this one might add, that similarly to a spoken language, and as implied by Aesop’s Fable “The Town mouse and the Country Mouse”, the learning of this specific city language is a prerequisite for the individual’s survival.

The links between language and cities can be further elaborated. Just think of the fact that a city is full of language and texts; each city, neighborhood and street has a name, roads are full of textual instructions (stop, no-entry, …); that in many cities different parts/neighborhoods of the city differ in both their morphological language (“face of the city”) and the language spoken in them (e.g. China Town, little Italy). In fact, the dyad city-language requires a separate study that is beyond the scope of the present book.

How can we quantify the OP language? The only way known so far is by means of the number of individuals who speak that language. And how can we quantify the OP city? As we’ve seen above, one possible way is by means of the number of inhabitants. Under the simplifying assumption that all the members of a nation/society/state and city speak the same language, we immediately can formulate an OP equation for a language and/or a city: it is the Verhulst equation

$$\frac{dq}{dt} = \lambda q - q^2$$ (11.2)

where $q$—is, in the case of a city, the number of citizens, while in the case of language, the size of the OP “language”. $\lambda$ and $\gamma$ are control parameters. In case there is an immigration of people who already speak the considered language (e.g. from the rural countryside to big cities), we may add to (11.2) a fluctuation force $F(t)$ in accordance to Sect. 10.4.

To take care of realistic situations (e.g. foreign immigrants arriving to a country’s cites), we must widen our approach by taking account of several languages and their interplay. For simplicity, first we consider the process in only one country or even one city. We assume that each inhabitant speaks only one language, say language 1 or 2. Then there are $q_1(q_2)$ individuals who speak language 1(2). Both languages “live” on the same “substrate” total population.

$$q_1 + q_2 = q$$ (11.3)

Thus the Verhulst equation (11.2) generalizes to

$$\frac{dq_1}{dt} = \lambda_1 q_1 - \gamma_1 q_1(q_1 + q_2)$$ (11.4)

$$\frac{dq_2}{dt} = \lambda_2 q_2 - \gamma_2 q_2(q_1 + q_2)$$ (11.5)
The coexistence of $q_1, q_2$ requires

$$q_1 \neq 0, q_2 \neq 0 \quad (11.6)$$

which entails in the steady state

$$\lambda_1 - \gamma_1 (q_1 + q_2) = 0 \quad (11.7)$$
$$\lambda_2 - \gamma_2 (q_1 + q_2) = 0 \quad (11.8)$$

These equations can only be fulfilled if

$$\frac{\lambda_1}{\gamma_1} = \frac{\lambda_2}{\gamma_2} \quad (11.9)$$

which is a very specific condition that implies that the coexistence of languages is a very rare event. A similar phenomenon is known of the coexistence of biological species which live on the same resource. A stable situation is possible only in ecological niches, e.g. by the occupation of different territories. When in a country or a city different languages coexist, then there must be specific “ecological” niches that may be based on more or less pronounced spatial separation, but also on special uses, e.g. scientific language, or dialects used just at home. In these cases, the resources become separated, and (11.4), (11.5) can be replaced by two independent Verhulst equations.

### 11.3.2 Language Families/Hierarchies

As noted in Sect. 11.1, languages (spoken and urban) can be imported into other countries by immigration which entails a change of language, say from English-English to American English etc. While in the new territory, say North America, originally the imported language is the same as that of the country the immigrants stem from, in both parts of the world the languages develop in separated biotopes. Just think of Australia’s fauna.

Besides by immigrants, a language (as well as urbanism with specific language of cities) can be brought to another territory also by conquerors, intruders, occupiers who force the subjected people to use the new language either completely or as a second official language. In some cases this adoption of a second official language may happen for practical reasons, for instance as unifying communication means in countries with many languages or dialects. In a number of cases, and at least formally we may define a language (OP) hierarchy such as in Fig. 11.3.

We have said “formally” because there is a fundamental difference between Figs. 11.2 and 11.3. In Fig. 11.2 we could distinguish between the OPs of the second
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layer by means of the numerical value of the bias value “b” of RFT which in turn is based on the individuals’ behavioral traits, whereas a quantification of the differences between languages is, at least presently, out of reach, and couldn’t serve as an explanation anyway. Rather, as noted above the differentiation between different OPs has its roots in the historical development.

Figure 11.3 can also be visualized in terms of Wittgenstein’s (1953) family resemblance category as a chain of languages/dialects which differ for neighboring territories only weakly, but become at larger distances with more different dialects in between, incomprehensible. Wittgenstein’s main concern was ‘what makes a category? If you look at the various proceedings that we call “games”, he wrote (ibid), “You will not see something that is common to all, but similarities, relationships and a whole series of them at that…”’. Portugali (2000, 2011) applied the family resemblance notion, in conjunction with the SIRN process, to the evolution and space-time diffusion of the entity/category ‘city’ in the last 5500 years. The same, as just noted, applies to the space-time diffusion of languages and their dialects. In Fig. 11.3 the OPs of the dialects form layer 2.

11.4 OP Diffusion

As noted in Sect. 11.1, OPs can diffuse from one territory/country to another. One example is language diffusion, another example is the diffusion of urbanism—the language of cities. To derive a diffusion equation for the corresponding OP we recall that a language (and a city) is attached to individuals. We consider the migration of individuals from one territory/city 1, to another one 2. The number of individuals in \( j, j = 1, 2 \), is denoted by \( q_j, j = 1, 2 \). Since in the migration process the number of individuals remains constant,

\[
q_1 + q_2 = N, \quad N - \text{total number of individuals} \tag{11.10}
\]

The random migration process can be modelled by means of a master equation of the general form (6.15) Sect. 6.1. Here we may specialize the state vector \( q \) to \( q \)
\( (q_1, q_2) \). Then we are concerned with a master equation for \( P(q_1, q_2; t) \). Because of (11.10), we may eliminate \( q_2 \), so that we have to deal with a probability distribution \( P(q_1; t) \). For a short-hand notation we write \( q \) instead of \( q_1 \). Note that \( q \) is now a single variable. The master equation of \( P(q; t) \) describes the change of \( P(q; t) \) in a very short time-interval. Therefore it is highly improbable that \( q \) changes by the simultaneous migration of two or more individuals. In other words, we need to consider changes of \( q \) by only one “unit”. In accordance with (6.15) Sect. 6.1, we denote the transition probability per unit time from a state \( q \) to a state \( q' \) by \( w(q'; q) \). (Note that \( w \) must be read from right to left). Having in mind our above remarks on the possible transitions, we arrive at the following master equation

\[
\dot{P}(q; t) = w(q; q + 1)P(q + 1; t) + w(q; q - 1)P(q - 1; t) - P(q)(w(q + 1; q) + w(q - 1; q)) 
\tag{11.11}
\]

We may simplify the notation by the following observation:

\( w(q; q + 1) \) means that the initial state \( q + 1 \) is lowered by one unit.

Thus we may introduce the notation

\[ w(q; q + 1) = w_-(q + 1) \]

and simultaneously

\[ w(q; q - 1) = w_+(q - 1) \]
\[ w(q + 1; q) = w_+(q) \]
\[ w(q - 1; q) = w_-(q) \]

With these denotations, (11.11) acquires the form

\[
\dot{P}(q; t) = w_-(q + 1)P(q + 1; t) + w_+(q - 1)P(q - 1; t) - (w_+(q) + w_-(q))P(q; t) \tag{11.12}
\]

Now we perform the decisive steps: Since in practice \( q \) is a large number, “1” can be considered as a small quantity \( \varepsilon \). To express this formally in (11.12), we replace there “1” by \( \varepsilon \) and expand the right hand side of (11.12) into a Taylor series up to 2nd order, where we use

\[
P(q \pm \varepsilon) = P(q) \pm P'(q)\varepsilon + \frac{1}{2} P''(q)\varepsilon^2 \tag{11.13}
\]

\[
w_-(q + \varepsilon) = w_-(q) + w'_-(q)\varepsilon + \frac{1}{2} w''_-(q)\varepsilon^2 \tag{11.14}
\]

\[
w_+(q - \varepsilon) = w_+(q) - w'_+(q)\varepsilon + \frac{1}{2} w''_+(q)\varepsilon^2 \tag{11.15}
\]
The dash’ indicates derivative with respect to $q$. The next steps—inserting (11.13)–(11.15) in (11.12) and rearranging terms—is a bit cumbersome so that we just quote the final result

$$
\dot{P}(q; t) = \frac{d}{dq} ((w_-(q) - w_+(q))P(q; t) + \frac{1}{2}(w_-(q) + w_+(q))\frac{d^2P(q; t)}{dq^2}
$$

(11.16)

Because $q$ refers to the number of individuals, $q \geq 0$. This implies $P(q; t) = 0$ for $q < 0$ and the boundary condition $P(0; t) = 0$.

Evidently (11.16) is a Fokker-Planck-$\hat{I}to$ equation where we may identify

$$w_-(q) - w_+(q) = -K(q)$$

(11.17)

$$w_-(q) + w_+(q) = Q(q)$$

(11.18)

The explicit calculation of $w_-, w_+$ or equivalently $K$ and $Q$ must be left to special models. One such model was sketched in Sect. 11.2 and will be treated in more detail in Chap. 13. A particularly simple case results if $w_-(q) = w_+(q) = w = \text{const}$.

If $K \neq 0$ this may reflect e.g. a social pressure in territory 1 (remember $q = q_1$!) so that people tend to emigrate. But this must be left to more detailed social studies and models.

A final note may be in order: the diffusion processes eventually lead to a steady state where $\dot{P}(q; t) = 0$.

### 11.5 Concluding Remarks

Cities, as emphasized in Chap. 2 and subsequent chapters, differ from material and organic complex systems in that they are hybrid complex systems. This difference shows itself also with respect to the properties of their OPs, slaving and circular causality in the context of cities: Following its emergence, an OP undergoes space-time diffusion processes that entail variations in its content. While this property was identified by us with respect to cities, it turns out that this is a property of many other systems associated with human culture and society. In this chapter we considered the example of languages in conjunction with the dynamics of cities. Yet it seems that similar considerations apply to other manifestations of collective human culture and behavior (cf. Sect. 11.1) that will have to be explored in the future.
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