9 Networks of Human Culture

Now that you are back from the zoo, where you tried in vain to shake the six hands of all the ants for several hours,[1] it is time to start our fifth trip into Netland. Let us go and see what those macroscopic ants known as human beings can achieve. I will show you what type of networks we have figured out to support the last variety of social networks from the previous chapter.

9.1 The Language Net

Ants build nests, bees have hives, and both dance if they want to pass on information. We talk. "Words in human language interact within sentences in non-random ways, and allow us to construct an astronomic variety of sentences from a limited number of discrete units" (Ferrer Cancho and Sole, 2001). Indeed, the human language is a complex network, where stability can be defined as the stability of meaning.

The words of our texts have both a high level of clustering and a small path length, which makes the language net a small world (Ferrer Cancho and Sole, 2001; Steyvers and Tenenbaum, 2005). Moreover, words display a scale-free distribution, the so-called Zipf law (Skinner, 1937; Zipf, 1949). In the Zipf analysis, all words are arranged in a rank order from the most frequent to the least frequent. Interestingly, the most frequent words have the least semantic content (e.g., 'the', 'of', to name but two). The scale-free distribution of words can be explained as a balance between the minimal effort of the speaker who aims to use as few words as possible, and the minimal effort of the listener who aims to understand the message in as unique and precise a way as possible (see Fig. 9.1) (Ferrer Cancho and Sole, 2003). This explanation shows a kind of self-organized criticality phenomenon in

[1] If you have just opened the book here, you might think that this is an autobiography from a madhouse – if you feel uncomfortable with this notion, please turn back a page and read the end of the last chapter.

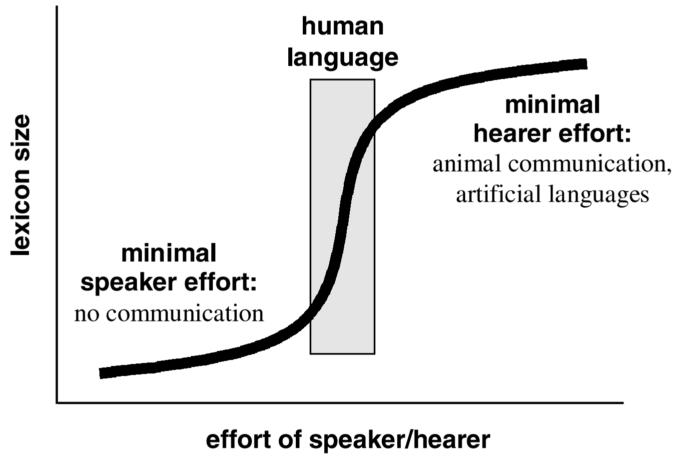

Fig. 9.1. The scale-free distribution of words: a balance between minimal efforts. The scale-free distribution arises as a balance between the intention of the speaker to use as few words as possible, and the minimal effort of the listener to understand the message in as unique and precise a way as possible (Ferrer Cancho and Sole, 2003)

language development. However, there may be other contributors to the surprisingly universal basic structure of our languages. Music has scale-free loudness and pitch fluctuations. Similarly, our speech also has a scale-free loudness pattern (Voss and Clarke, 1975). Whether the tonality of pre-languages also had a scale-free pattern, and if so, whether it influenced the development of the scale-free textual pattern of modern languages, is not actually known. Moreover, the systematic analysis of the possible influence of scale-free neural and cognitive patterns on the development of their textual representation is also in its early stages (Steyvers and Tenenbaum, 2005).

Besides the minimum number of words contra their maximal uniqueness, language has the same inherent ambivalence at a higher level. Indeed, it has to have a high degree of structure and at the same time it has to be highly informative. The high degree of structure gives us a minimum number of structural variations, while the high information content assures the maximal uniqueness of the meaning. These ambivalent features increase the complexity of language (Crutchfield, 1994).

Weak links are necessary for complex communication. If we imagine a hypothetical language where all words have a unique and exclusive meaning, with no ambiguity, no explanatory digressions, and no redundancy, then we end up with a rather simple language. As an example, you may think about the 'language' you use with your dog. "Sit!", "Stop!", "No!" are pretty clear messages, provided the dog is in the right mood. The transmitted information is focused, but not really complex. As another example, I remember when staying in London for a language course with my father and brother, we swore that we would talk to each other only in English. Keeping strictly to our promise as we walked into the Tate Gallery, we could only make the very same remark to one miracle after another: "How nice!" We soon felt like a bunch of morons and switched to Hungarian. Indeed, the meaning was focused and correct, the Turners and Blakes were indeed all nice there, but the complexity of their beauty required a larger vocabulary, with more degeneracy and ambiguity, and hence with more weak links between the words.

The language net can be divided into modules. Language modules have been defined via at least three highly different approaches. One of these stems from studies on cognitive deficits and language development (Levy, 1996). Another approach uses the relationships between the order of words conveying a meaning (the syntax) and the concepts covered by the words (Chomsky, 1957; 1968; 1975; Maynard-Smith and Szathmáry, 1995). The third type of language module definition arose from language usage and social dimensions. I will elaborate on this third modular description in some detail.

In language modules defined by social dimensions, we have a core module with a starting set of 300 to 400 words and all its variable extensions right up to Shakespeare and Ray Bradbury. There are various parallel modules, like slang, subspecifications of the scientific language, etc., which are all used by smaller modules of the society. These are extended, modified or replaced by regional modules which sometimes remain quite isolated, like versions of pidgin English.

Members of a society simultaneously use different language modules. The number of language modules depends on the number of social dimensions of their owner. The higher and the more diverse the social dimensionality of a society member, the richer the language she speaks. In this context it is not surprising that, from early childhood, rich and complex expression is an important factor of social success. Groups tend to select their leaders from those who speak more language modules, who have a higher number of social dimensions, and whose cognitive flexibility is greater. As I will describe in the synthesis of Chap. 12, cognitive flexibility leads to a better resolution of conflicts. Besides vision and willpower which set and maintain the goals of the group, skill in conflict resolution is a highly valuable leadership quality in a group which hopes to solve a complex task and to do it in an optimal way. This skill is usually first revealed by the number of language modules the owner is able to master.

Weak links help to renew a language. The contacts between the modules of the language net are usually provided by weak links of the social net. [As an example of this, a rare visitor to the Papua New Guinea tribe brings the word 'nettouck' (i.e., network) to the pidgin English vocabulary.] This role of weak links in language renewal (Milroy and Milroy, 1985) is very similar to the role of weak social links in the spread of innovations, as described earlier.

Ambiguity in our expressions arises from the same degeneracy that was detailed in Sect. 4.5 (Edelman and Gally, 2001) and leads to the emergence of weak links in the language network. Plural meanings of the same word provide an opportunity for more delicate expression, where the environment of the word profoundly influences its final meaning. Ambiguity is highly characteristic of the most frequent words with the least semantic content (Ferrer Cancho and Sole, 2003). An optimal amount of ambiguity, paradoxically, but in agreement with the role of the weak links it generates, stabilizes the meaning of the text as a whole. In the following points, I will list some examples relative to this statement:

- If we would like to get a proof of understanding, we do not ask for word-for-word repetition, but require a reformulation of our thoughts using different words (Pleh, 1988).
- If we want to know the meaning of a simple word in a foreign language, it is not enough to check 'the' corresponding word in a vocabulary list. First of all, there will be many possible meanings. To train our minds to grasp the extensions, modalities, and frequencies of the 'meaning field' of a particular word, we need to do quite a bit of 'networking'. When doing this, we check synonyms, expressions, etc. Moreover, to figure out the exact meaning of the word in its original place, we need to know its context in detail (Deacon, 1997). Many of the steps described here invoke a large amount of ambiguity, which helps to shape and stabilize both the complex and the actual meaning of the word. The more unusual the meaning of the text, the more stabilization it needs.

Ambiguity is all the more important in the stabilization of the language, since our language changes extremely rapidly due to the fast changes of social structure and the links it helps to represent (Dunbar, 2003).

Not surprisingly, ambiguity is an important element of any creative behavior, be it poetry, science or any other. As one of the related examples, scientific excellence has been shown to parallel tolerance of ambiguity (Stoycheva, 2003; Tegano 1990).

As an indirect example of ambiguity-induced stabilization, ambiguity helps arbitration. When two parties find a difference in their interests which cannot be bridged by any reasonable compromise, "ambiguity can be employed as a tool in achieving an adequate, if imperfect, settlement of the dispute" (Honeyman, 1987). Here ambiguity gives stabilization at another level, not by building weak links within the text, but by building weak links of both parties to the text. Although these links point to different segments or meanings of the same text, the fact that a commonly accepted text could be achieved without any negative ramifications tends to stabilize the situation.

A minimal ambiguity may act as a destabilizer. Ambiguity has to reach a threshold to act as a stabilizer. If ambiguity is below this threshold, the amount of weak links is not enough to make the meaning stable, but the remaining ambiguity is enough to cast doubt on the meaning itself. A rather absurd situation comes to mind to illustrate this. Our neighbor, Tante Sissi, was unbelievably old (at least for my seven-year-old mind) when she died. She had quite a number of friends living in Austria. One of them, a very respectable old lady, arrived a few weeks after Tante Sissi's death. I was the only person at home. My mother had taught me not to open the door to strangers. I observed the respectable old lady through a small window as she inquired about Tante Sissi, who had not written to her for a long time. My German was not that great, and I was also rather embarrassed by the situation, so I could tell her only the basic fact: "Tante Sissi hat gestorben." (Tante Sissi died.) The brutality of the statement made it unbelievable. Noticing the misbelief, I began to doubt whether my German was correct. Here the situation grew into an absurd modern drama: I disappeared into the room to look for a Hungarian–German dictionary, found 'died' in Hungarian, and pointed to the German version: 'sterben' in the dictionary. The lady began to cry. So did I. We kept crying for a while, each seeing the other's crying face framed in the small window. Here ambiguity was not enough to stabilize the message by putting it into a context. There were no polite preliminary sentences to prepare the lady for the bad news, and the short sentence had no emotional background to show her my participation, sympathy and consolation. However, lacking any skill in the language, there was still a remaining element of ambiguity (bad pronunciation, inappropriate intonation, etc.), and the message had therefore to be reduced to the level of absurdity to get it through.

Degeneracy is not only present in the form of ambiguity in our language. Small-talk also brings degeneracy to the semantic context of the discussion. The core of the information transmitted by small-talk is redundant due to previously known facts in most cases. However, the way the core information is presented in this form of communication builds up several layers of extended context and enriches the meaning. The degeneracy that arises develops weak links, which help to stabilize both the meaning and the community circulating the message (Dunbar, 1998).

9.2 Novels, Plays, and Films as Networks

When we construct a meaningful text, we build up each sentence from words which support each other and make the meaning of the sentence into a coherent whole. "Similarly, when we construct a paragraph of several sentences we make them support one another to form a meaningful paragraph. And the process continues, throughout a meaningful document, so that a meaningful text is evidently constructed by a recursively defined process: a meaningful text is an interdependent sequence of words and/or meaningful texts" (Scarrott, 1998). *"To be honest, when I am trying to follow your ideas, Peter, I have to say that quite often I do not see this 'recursively defined process' resulting in an 'interdependent sequence of words'."* Spite, you will be surprised. In spite of your continuous efforts to interrupt the interdependent sequence of my words, the text of this book is still a network. Let me give you just two significant examples to support this. If you carry out a statistical analysis of the references from this book (as a member of the LINK group, István Kovács, did), you will find that their frequency distribution follows a scale-free pattern. Moreover, the cross-references make the book into a small world. While writing these sentences, which seem to be fragmented to your young mind, Spite, I have made a well-organized network.

Stiller and Hudson (2005) showed that scenes from Shakespeare's dramas all describe a small world. Small-worldness is probably a general feature of all texts and serves the cognitive needs and capabilities of the audience. Moreover, the small world of the Shakespearean drama is constructed by . . . , but perhaps I should ask you to guess? Yes, you figured it out correctly. The small-world of the Shakespearean drama is constructed by weak links. Scenes are connected by 'keystone' characters transmitting a minimum of necessary information to understand the connections between actors of the previous and the present scene. Actors of various scenes are involved in an intensive interaction with each other (developing strong links), but are linked only weakly to actors of other scenes by the keystone characters. Thus the keystone characters and the weak links they provide stabilize the network and the meaning of the whole play. In fact, this feature significantly contributes to our impression of complexity in Shakespearean drama, where the structure provides an optimal mix of segmentation and continuity (Dunbar 2005; Stiller and Hudson, 2005).

Superman as a WEAKLINKER. Modern cartoons are not about Hamlet, Gloucester, Romeo or Buckingham. Superman, Spiderman, or whateverman is the hero of modern times. He is omnipotent and generous. He helps everyone. He does not usually have a particularly stable family. He has lost his parents and had platonic love affairs, and he is a kind of angel figure. From the network point of view, supermen are typical WEAKLINKERS. They not only stabilize the story network and the diegetic landscape of the cartoon or film. They stabilize the diegetic world as well. Wherever they go, things get back to normal.[2] Everything seems to be quite clear, except one element. If social networks traditionally have women in the role of WEAKLINKERS, when shall we have a spiderwoman? As a possible answer, Hollywood may be promoting gender relativism with this message. Men should take over a part of the female tasks that go to forging weak links in order to allow women to participate better in male tasks. This also accelerates the link relativization mentioned in Sect. 8.6.

Let us return to Shakespeare. The comprehension of drama (novels, films, etc.) is governed by a match between the drama and the audience (Gallese and Goldman, 1998; Stiller and Hudson, 2005). In the optimal case, a very interesting and novel type of synchrony may develop between the dynamics of the drama network, and the neural state of the audience, both as a number of isolated individuals and as a synchronized network in itself. Obviously, the synchronized network

[2] I am grateful to István Kovács for this idea.

Fig. 9.2. In the optimal case, a very interesting, novel type of synchrony may develop

of the whole audience may only develop if several people watch the drama or movie at once. The probability and extent of this synchrony is determined by the pre-set cognitive and emotional schemes of the target person or persons. A synchronized synchrony of the whole audience requires a resonance between the drama and the joint cognitive and emotional schemes of most of the audience. If such a synchrony is achieved, a synchronized psychic relaxation may occur, which is called catharsis.[3]

At first glance, it was somewhat easier to reach catharsis in the ancient Greek and English times than it is now. People ate the same, had more or less the same troubles, and many of them knew each other personally and formed a rather closed community. Whom do you know in the darkness of a modern movie or traditional theatre? Still, we had masterpieces more than two thousand years ago, and we have them today. The question arises: what makes a masterpiece a masterpiece? *"My literature teacher drives me mad with a similar question: 'What might Shakespeare*

[3]Catharsis is similar to the synchronized laughter quake mentioned in Sect. 3.5.

have been thinking about when he wrote these lines?' Do you want to start the same game here? I am just asking you this because Pity and I are then leaving for a while." The answer to this question will be rather limited, adding only two new aspects, namely, networks and their synchronicity, to the wealth of previous attempts to solve the mystery.

What makes a masterpiece a masterpiece? Synchronization and resonance can obviously be achieved at the level of the story, values, etc. However, most of them are not network properties and are not even general enough to grant masterpiece status to the work for any extended period. Dunbar (2005) lists properties such as the correct reflection of evolutionary principles (like the protection of kin, rules of mate selection) as an important element of success. Using my limited network-oriented view to explain a long-lasting impression, sync can be achieved by mastering general network properties, i.e., small-worldness, scale-freeness, etc. We have already seen the small-worldness of the Shakespearean dramas (Stiller and Hudson, 2005). Does this property reach the masterpiece level? Dunbar and his colleagues' response is affirmative. They note that cast size usually matches the size of human networks, 25 to 35 individuals, which is the number of your average colleagues and pals, and the number of characters active in a scene at any one time is identical to the size of natural human conversations, involving a maximal number of 4 actors. Moreover, the internalization of the intentions, motivations, words and deeds of the 4 actors requires the audience to think to the fifth order, so to speak. A typical sentence to reflect this complexity is the following: I believe that A supposes that B intends to guess how C understands what D thinks. According to Dunbar's measures, fifth-order thinking is the usual cognitive limit. Thus a masterpiece works right at the cognitive limits of the audience. Why is a master a master? She (or in Shakespeare's case, he) has to work one order higher! The typical sentence is changed here to the following: the master supposes that the audience will believe that A supposes that B intends to guess how C understands what D thinks. Why do we not have more Shakespeares? There are only a small number of people who are able to work to the sixth order (Dunbar, 2005; Dunbar et al., 1994; Stiller et al., 2003).

More secrets of masterpieces. *"Preparing my final exam in high school, I have to read a lot. Let me assure you, Peter, that not all masterpieces are dramas. We have quite good novels with a few actors or with no actors* *at all. How do these novels achieve their synchrony?"* The language net provides a lot more options for obtaining a sync feeling from the reader. Now here comes my other hero: scale-freeness. In Sect. 2.2, I mentioned a number of evolutionary and other reasons explaining why we like scale-freeness. I also mentioned that music contains a lot of scale-free distributions. Novels may not be exceptions. I already mentioned that the occurrence of the references of this book also has a scale-free distribution, which probably reflects the rank of importance of the works quoted. There seems to be nothing special in this, since many scientific papers examined so far by LINK member István Kovács have the same distribution statistics. However, real masters may add several layers of scale-free complexity. They may employ a scale-free distribution of link strengths between various actors.[4] The master may incorporate scale-freeness by the use of structural elements (conversations, dreams, changes in the line of the plot, etc.), motifs (metaphors, unusual words, symbols, colors, smells, etc.) or conceptual elements (ideas, values, etc.). Scale-freeness may be present in all these, simultaneously giving a rich pink-noise network to the novel, the masterpiece. *"Peter, do you really think that poor old Tolstoy sat with a 'schoty' (just for you Peter, this is the Russian name for an abacus) calculating whether he had already reached a simultaneous scale-free distribution of the thousand things you listed in* **War and Peace***? Peter, this is absurd."* No, Spite, have you ever seen me checking whether my references have reached a scale-free pattern? I have never done that. But the references still have a scale-free distribution. In Tolstoy's head, the whole statistics was just there in its whole marvellous complexity. Moreover, great masters will certainly introduce novel quakes by building up a tension in the novel and than allowing a delayed but sudden relaxation. They will also use topological phase transitions in the textual network of the novel, synchronicity of all the elements listed above, and many more.

Network secrets of Greek and Roman mythology. A recent report by Choi and Kim (2005) analyzed the virtual network of 1 647 gods, heroes, monsters, mortals and fairies in the Greek and Roman mythology. They found a scale-free degree distribution of the actors in the mythology network, which was a hierarchical small world.

[4] We usually have a main actor, a few key actors, some important roles and several minor roles; in inverse proportion, we learn a lot about the character of the main actor, somewhat less about the key actors, usually a single feature concerning the important actors, and practically nothing about the minor roles.

When the master goes too far. What happens, if the master is too unique? How will she be understood if she has inherited an exceptional brain which works not only to the sixth, but also to the seventh, eighth or even higher order (Dunbar, 2005)? We have two options here: the sync of her work (1) either contains a sub-network, which produces sync at the fifth order, and it will be a masterpiece, or (2) it contains a masterpiece at the seventh order which can be understood and enjoyed by approximately a dozen people on Earth (all fellow masters themselves, who are obviously biased). In the latter case, the master can only hope that evolution will make our brain capable of working to higher orders in the future and that she will be rediscovered in the 33rd century.[5]

Masters of the future. Oral communication proceeds using multiple layers of metacommunication. On the other hand, its transcribed versions have to cope with a one-dimensional chain of information (Nyíri, 2003). Over the millennia, masters have become able to construct a multidimensional rhythm and excitement cross-connecting the one-dimensional flow of words. Digital multimedia documents have the advantage of starting from the network-type organization of hypertext and from the multiple dimensions of sounds and image. Mastering and understanding the single dimension took us several thousand years. Hopefully a little respite in today's technical developments might allow the human brain to discover the further cognitive abilities required to create and enjoy the synchrony of multidimensional possibilities.

Are the great masters healthier? The complex interaction of actors and their possible reflection in the audience's and the master's brains makes me think about its similarity with the idiotype network introduced by Jerne (1974) and mentioned in Sect. 7.1. This network can be described by: a lymphocyte I acts on antibodies of lymphocyte A, acting on antibodies of lymphocyte B, acting on antibodies of lymphocyte C, acting on antibodies of lymphocyte D. Is this not rather similar to the network: I believe that A supposes that B intends to guess how C understands what D thinks? Immune cells are similar to neurons in a number of ways. Could this be one of them? In most cases, the cross-reaction of lymphocytes decreases rather abruptly after the third–fourth interaction (Ab3/Ab4),

[5] Actually, it would be extremely interesting to make an 'order analysis' of some masterpieces recently rediscovered just to see if we are already a bit better off than our ancestors. Reading Shakespeare, one doubts this.

and the sixth–seventh interaction (Ab6/Ab7) can be regarded as exceptional (Bona et al., 1981; Weisbuch et al., 1990). Complex idiotype repertoires are characteristic of early childhood and they decay later. Do some people keep them much more than average? Do great masters have a more complex anti-idiotype network? Are great masters healthier? *"Peter, I am beginning to doubt whether it was worth staying. First of all, why should there be relationship between a more complex anti-idiotype network and better health? Secondly, you yourself have quite often mentioned Mozart. He was a great master, as I hope we may agree. But was Mozart healthier? The poor guy died at the age of 35 probably from eating undercooked pork and getting trichinosis, which is a bunch of ugly worms enjoying themselves in your muscles (Hirschmann, 2001). Do you call this exceptional health?"* Well done, Spite! Thanks for the reference. However, even if this was the case (which is debatable, I suggest you read Dupouy-Camet, 2002), I do not think that a better immune system can necessarily fend off a massive parasite contagion. However, in answer to your first question, I must admit that I have no evidence for saying that a more complex immune network leads to any advantage in health.

The network approach has taught us an important lesson: a masterpiece is a masterpiece because it provokes a synchronized psychic relaxation of the audience,[6] ensuring both group cohesion and the safety of its members (Dunbar, 2005). Most masterpieces work at the limits of our cognition, and provide a complexity of network structure and dynamism which by itself provokes a relaxation, i.e., catharsis, in the reader or spectator.

The nested sync of masterpieces. Spite, this is the moment to take your leave with Pity. In Sect. 7.5, I was talking about synchronization events which may occur between various networks, proposing the hypothesis that, if the synchronization within a network is exceptionally well organized and strong, it may provoke the synchronization of a network one or more levels higher. A real masterpiece certainly reflects the sync of the master's mind and in turn induces the synchronization of the reader's neurons.[7] However, a masterpiece also induces the synchronization

[6] To understand the generality of this, you may remember here the cathartic effect of any 'Aha!' phenomenon or extensive laughter you have experienced in the past.

[7] It would be a nice experiment to compare the neuronal synchronization level when reading Tolstoy and a bad contemporary Russian writer. Moreover, the comparison of the sync of Tolstoy's mind and the bad contemporary writer's mind would certainly have been a great piece of study.

of a whole audience, and maybe of mankind as a whole! (Before you protest I remind you again that we are in a three-smiley box. Watch my hands! I am cheating!)

Now take a deep breath, drink a glass of crystal clear water, relax, and most importantly: think. *If you want to be a master*,[8] you have to practice. *"What should I practice?" Practice empathy*. Try to understand how others think. What are their beliefs? What are their motivations? Why do they do what they actually happen to do? Play around with it. Move the center of your thoughts from your own head to theirs. Look around with their eyes and try to get an idea of what the world looks like from this new vantage point. And make a careful note here: this is *not* only an altruistic act, which will help to stabilize the world around you. This is also the key to your own success. However, there is one more important note here. If you succeed in understanding how a person thinks but that person is similar to you, then you will have achieved practically nothing. If you succeed in understanding someone who is separated from you by a world of cultural features, customs, and beliefs, *that* will be the point when you may begin to aspire to being a real master.

9.3 Our Engineered Space

When I first inserted the title of this section in the book, I wanted to find the answer to a question which has haunted me for a long time: Why do people like Budapest? As I organized a world congress in my home town during the preparation of this book, I often heard the remark: "Oh, Budapest! I have been there, and I return whenever I can." But why do they want to return? Whenever I ask the question, I do not really get a convincing answer. Yes, life is reasonably cheap, the food is good, the wine is fine and Hungarian girls are pretty (Spite, you may stop your glorious smile and vigorous nodding). But you can find all this in a great many places in the world. So I kept on asking and in the end my poor respondents could not say anything else but: "You know, Peter, Budapest is a cosy place. We feel well when walking in the streets and looking around."

They might be right. I feel extremely well myself when walking around in Budapest, Paris or Venice, just to name a few of the great

[8]The term 'master' does not refer only to a master of drama or creative writing here. As you will see in Sect. 10.1, a market guru uses the very same cognitive abilities.

cities of our world. In contrast to this, I remember my discomfort when walking around in Kuala Lumpur. The buildings were beautiful and life was ultramodern, but still, I could not enjoy it. It took me days until I realized what the main reason was. I could not walk straight without feeling perturbed. After 3 to 4 meters I either had to change direction, or step down from the enormously high sidewalk and then step up again. I discovered in Kuala Lumpur that space distribution can be crucially important for one's personal comfort. Let me mention two more personal examples, and then I will revert to the scientific approach. Space distribution is not only an issue for town planning. It is also a key point of architectural design. When a new plaza was opened in Budapest, I felt awful when I visited it first. It was alienating and empty. I went there half a year later and entered a different world. I felt quite at home. Wow! Was I in the same place? What had happened there? Practically nothing. Only a few kiosks, benches, and flower boxes had been added. But could it make such a vast difference to break up an empty space in such a subtle way? My last examples are Epidauros and the Summer Palace in Beijing. It may be surprising to find them in the same paragraph. However, it was not the building which made this everlasting impression on me in these places, but the landscape. The harmony and the rhythm of the hills one behind the other was the real treasure of these two magnificent places. I learned that space distribution is extremely important for a good life.

Let me start as I did two sections ago: Ants build nests, bees have hives, and both dance if they want to pass on information. In that section, we examined our human copy of dancing: language. Now we shall examine the human version of nest-building, i.e., our engineered space. Staying for a second with animals, I shall use mole-rats as my first example. Mole-rats dig a rather extensive place to live in. The burrow of the naked mole-rat may exceed 3 kilometers in length and has a complex structure with different parts serving as foraging galleries, nest chambers, food stores, and toilet chambers. Mole-rat burrows have scale-free distributions. They are fractal-type objects (see Fig. 9.3) (Le Comber et al., 2002). This structure is due to the very same Levy-flight search statistics (Levy, 1937) I discussed in Sect. 2.2. If a mole-rat wants to explore its environment for more food in the most efficient way, it has to make the same area-restricted search with a scale-free distribution as albatrosses, ants, bees, deer, fruit flies, jackals or monkeys (Atkinson et al., 2002; Cole, 1995; Ramos-Fernandez et al., 2004; Viswanathan et al., 1998; 1999).

Fig. 9.3. The fractal properties of mole-rat burrows. The figure shows a schematic representation of a burrow of the mole-rat, *Cryptomys hottentous*, in a mesic environment. The burrow has a scale-free distribution of route lengths, which infers a fractal property. (Reproduced with kind permission from Le Comber et al., 2002). Natural or architectural objects are not pure mathematical fractals and their self-similarity is rather limited

As already mentioned, Levy flight was developed as an optimal search strategy, and seems to be conserved throughout evolution. We are no exception. If we scan an image, our gaze shifts from one place to another, producing a Levy-flight distribution (Boccignone and Ferraro, 2004). If we browse the World Wide Web, we make Levy flights (Huberman et al., 1998). Humans display a consistent aesthetic preference for fractal images (Hagerhall et al., 2004; Spehar et al., 2003). The pre-set space is scale-free in our mind. When we build one, whether we like it or not, we have to follow this pattern if we want to make ourselves feel at home. Le Corbusier and other great architects may have wished to educate mankind differently, but no one should forget that this is a million-year project. Genes are slow. *"Peter, may I inquire what are you talking about? You seem to be fighting against something, but you have forgotten to define the goal!"* Yes, Spite, you are right again. Seeing our beautiful towns filled with the horror of block-shaped houses, and having dreamt in my childhood of becoming a sculptor or architect, this is a very important issue for me. I lost my temper and I am sorry about that. So let us start from the beginning.

In traditional architecture we have a lot of buildings which have a scale-free space distribution. This is usually called the fractal property after Benoit Mandelbrot, who discovered the generality of the scale-free space distribution of various natural (cloud, mountain, tree,

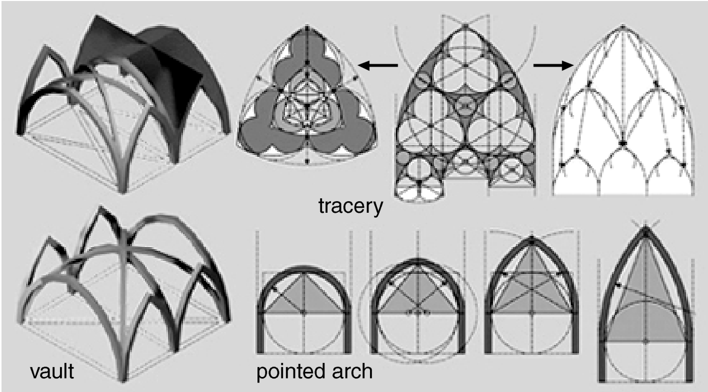

Fig. 9.4. Fractals in the Gothic style. The figure shows the fractal properties of the pointed arch, a major motif in the Gothic style. The variable, self-similar scales are highlighted. (Reprinted with kind permission from Lorenz, 2003.) Here again, self-similarity is not as pronounced as in a pure, mathematical fractal

snowflake) and man-made objects (Mandelbrot, 1977). Reims Cathedral in France, the Ca' d'Oro and the Palace of the Doges in Venice all have a scale-free pattern. They are self-similar. However, self-similarity is not always complete here, and does not extend to several scales but remains restricted to just a few. A great part of the exceptional beauty of these buildings comes from the fact that they have a fractal property (see Fig. 9.4) (Lorenz, 2003). Before Spite asks the same question as in the last section, when he mentioned Tolstoy's abacus, let me note that this part of fractal design was not planned. It came from the harmony between the old masters and nature. However, the architecture of the 20th century got rid of ornaments, porticos, gazebos and all the beautiful little adornments of past masterpieces. Several scales have simply been erased, striking a damaging blow to the scale-freeness of our evolutionary past.

A year after the English version of Mandelbrot's book (1977) was published, Peter Eisenman exhibited the House 11a project. Eisenman thought of fractals (scale-FREE-ness) as a mix of three destabilizing concepts: discontinuity, recursivity and self-similarity contradicting our presence, origin and aesthetic object, respectively (Ostwald, 2001). Fractal architecture became akin to chaos theory, turning the original idea upside down. Scale-freeness was not a result of organic development, but a negation of the order forced on us by the 20th century masters. Not surprisingly, the House 11a versions did not have much to do with comfort. The smallest house had human height but was obviously not a house, and the largest object was too large to be a house. Furthermore, the right-sized object was filled with an infinite series of scaled versions rendering it useless as a house. Still, the fractal design brought a great resonance, and within a decade several hundred works had been designed or published in the field (Ostwald, 2001).

Fractal architecture soon lost its appeal. In the 1990s more and more people started to criticize the initial zeal (Ostwald, 2001). However, the basic idea refused to lie down. When Carl Bovill (1995) published his well-balanced book on fractals in architecture, self-organizing, natural forms were slowly rediscovered and 'true' scale-freeness was reinstated: the scales that are really important to us in the centimeter to meter range regained their rightful place. Scale-freeness seems to be a key point of human-friendly architecture. However, the nodes of this self-similarity are also important. The non-metric system has some very good examples of this. If we miss, or under-represent the inch–foot–yard range in space, the building we get may conform to the purest 'fractalism', but it will lose any hope of being enjoyable. Space design has to achieve a synchronicity with our own human measures.

Cities are fractal (Batty and Longley, 1994; Portugali, 1999). One of the oldest scale-free distribution laws, Zipf's law of town-size distribution (Zipf, 1949) already shows the level of self-organization in cities. There have been many approaches to explain scale-free town development, such as the diffusion-limited aggregation model (Vicsek, 1989), the correlated percolation model (Makse et al., 1995), or the intermittency and cluster analysis models (Zanette and Manrubia, 1997). Many of these models reflect the fact that towns emerge from local actions, display a hierarchical modular structure, and grow in a way that obeys the Matthew effect mentioned in Sect. 2.2. Here the Matthew effect reflects the fact that the probability of the development of an area depends on the occupancy of its neighborhood.

What are the space representations of scale-freeness in our towns? We have the same situation here as in the great novels of the last section. In the case of organic development, a lot of measures become scale-free in a parallel way. We have a scale-free distribution of object sizes from the smallest element of shop windows up to the largest squares.[9] There is scale-freeness in the distance what we can cover

[9] This shows the utmost importance of keeping our shop windows full of exciting little treasures and not allowing them to be covered by a giant poster. It is not surprising that properly arranged shop windows are another hallmark of the best cities around the world.

undisturbed. Suburbs grow according to the scale-free rule (Makse et al., 1995). We have a scale-free distribution vertically as well, in the sense that most of the houses are rather small, but some are bigger, and a very few are really big. If we have beautiful hills around (but not all around!), that makes our situation much better. Towns are indeed fractal (Batty and Longley, 1994; Portugali, 1999; Vicsek, 1991).

"Let me ask a question here: are you suggesting that towns should be allowed to develop as they wish? Should we still swim in the organic sewage of the organically developed medieval towns?" No, from time to time we have to correct the organic development of our towns. When Haussmann designed the avenues and boulevards of Paris, cutting them into the flesh of the city, he just inserted the missing scale, which could not have been developed in the medieval town. Pope Sixtus V did the same with Rome. The same reason underlies the development of large parks. There can be no doubt that we have to help organic development. But we have to do it wisely. Nikos Salingaros (2004) listed a series of guidelines in his keynote speech to the 5th Biannual Congress of Town Planners in 2003:

- Re-establish and protect the small scales: pedestrian network, ornaments, kiosks, low walls for sitting, etc., to provide links with the town at the level of physical intimacy; increase contrasts to give visual excitement and make all this harmonically multifunctional to provide an emotionally nourishing physical environment.
- Slow down the big scales: highway construction, skyscrapers, suburban sprawl.
- Provide a scale-free green space distribution.
- Establish an organic integration of the 'electronic city'.

Other network features also operate in our engineered space. A good town is not only scale-free; it is also a small world, with a number of long-range connections, either in the traffic or at the level of the 'electronic city' (Salingaros, 2004). Moreover, a good town is nested. Its functions are mixed and intertwined (Alexander, 1965).

Architectural design reduced the diversity of 'modern' towns in the 20th century. Alternative routes were cut and *the* highway was continually widened and extended to serve increasing traffic levels (Alexander, 1965; Salingaros, 2004). The re-establishment of alternative paths would make a lot more weak links, which would help to stabilize town traffic. Similarly, the suggestion of mixing up the functional areas of the town, destroying the Le Corbusier-type home–office segregation

(Alexander, 1965; Salingaros, 2004), also gives rise to stabilizing weak links, as we have seen in many previous examples.

Extra care should also be taken here with regard to fringe areas. Like the brain or business organizations, the crossover areas of urban traffic have to be developed with extreme care (Salingaros, 2004). As an example, the area where you leave your car and walk to the subway is especially important. Here we should put a number of stabilizing weak links, like places where people can stop, sit for a while, or perhaps wait for each other and have a chat. Here we should pay special attention to scale-free distributions by introducing a lot of natural fractal objects, like trees and other plants of various sizes. What do we have today instead of these green community places? We have dreary concrete multistorey car parks and asphalt wastelands.

The last few sentences have touched upon another issue here. With proper planning, we are not only promoting weak links inside the urban traffic network; we are also promoting the formation of weak links between the inhabitants of the town. Therefore, in the same act, we achieve stabilization of the traffic and help to stabilize town life as well.

A properly engineered space is a masterpiece. It requires the same multitude of scale-freeness and synchrony as the masterpieces of literature I mentioned in the last section. This will bring a resonance and synchrony to visitors and inhabitants (Mikiten et al., 2000). This is the same magnificent, serene feeling that all of us may experience upon entering St. Peter's Cathedral in Rome or walking around a zen garden in Kyoto. The design of a masterpiece requires a master. This master does not have to understand human relationships to 6th order, like Shakespeare. This master has to understand a similarly high level of spatial complexity. This master has to have a high tolerance to the ambiguity of overlapping elements and designs (Alexander, 1965). This master has to think at least to the 6th order with regard to space. Modern engineering has become an art, as I will discuss in Sect. 9.5.

I think I have now found the answer to my question. We like Paris, Venice, Budapest and all the real towns of the world because we feel the harmony and wisdom of generations of great masters there. These towns give us the same joy of collective relaxation as laughter, clapping, Mexican waves in a stadium, or a great novel.

9.4 Software Nets

We have arrived at the last section on human-made networks. *"I am missing something here. Actually, not just something, but a LOT of things. Do you have nothing to say about power nets, communication networks, transportation networks, the Internet, the World Wide Web, electronic circuits and the like? Are human achievements limited to language, novels, space and software in your mind? Although I am now trying to empty my brain after my successful final exam at high school, my mind is still definitely broader than this."* Congratulations, Spite, on your successful exam! I do not doubt that your mind is broader than mine, since the IQ declines with age. Therefore I should be making every effort to catch up. However, let me assure you that it is not my proverbial absentmindedness that makes me leave out all the networks you so wisely listed. Some of these networks, like the power net, have already been covered, while my literature search in other areas did not lead to non-redundant information, besides the small-worldness, scale-freeness and nestedness of these other networks.

Software segments manifest network behavior with scale-free and small-world connectivity (Valverde et al., 2002; Myers, 2003; Potanin et al., 2005). However, software design differs from the other networks mentioned above. Evolvability, which means the possibility of highly flexible further development, is a primary concern here. Modern software is designed through a parallel process by many teams and individual developers. Consequently, modularity and hierarchy are exceptionally highly evolved in the various program packages and have become a key issue for software quality. The multidimensional and multifaceted links between modules have to be well designed (Gamma et al., 1994; Pressman, 1992). Modules are usually 'pre-fitted' to a large number of possible cooperating modules by implementing 'design patterns', constructing the intermodular fringe areas mentioned in the context of brain organization (Agnati et al., 2004), and in the last section. Design patterns are a form of pidgin formalization, facilitating industrial cooperation (Sabel, 2002).

The need for modular building extends to smaller segments, inducing the emergence of several well-known network motifs, such as feed-forward loops. In fact, software reverse engineering is a process for extracting these simple motifs from existing software and applying them for general use (Myers, 2003).

Software modules form two major classes with a large asymmetry between their incoming and outgoing contacts. Certain modules have a small number of incoming links and a large number of outgoing links.

These are usually large modules, performing a complex function that requires the help of several smaller, more general modules. The latter modules form the other class, with a large number of incoming links and a small number of outgoing links. These are small modules performing a simple function which is reused in various contexts by many larger modules (Myers, 2003; Potanin et al., 2005). According to the idea of Valverde et al. (2002), this distribution might have developed as an effort to minimize development costs by introducing an optimal trade-off between a small number of large, expensive components and a large number of small, cheap components. The diversity of uneven contacts certainly increases the chances for the emergence of weak links. This increases the stability of software systems, which I will describe in the rest of this section.

Several pieces of software have a bad smell. As one example, excessive use of hubs, which means highly connected modules here, is considered to be bad design practice and called an antipattern (Brown et al., 1998). This agrees with the scale-free link distribution mentioned above, which reflects the fact that, in complex software, modules with only a few links predominate. The software deodorant is called refactoring. Refactoring is "the process of changing a software system in such a way that it does not alter the external behavior of the code yet improves its internal structure" (Fowler et al., 1999). This definition of refactoring satisfies the functional definition of weak-link manipulation I gave in Sect. 4.2, following Berlow (1999). Several refactoring[10] steps introduce more links into the system (Brown et al., 1998; Fowler et al., 1999), and these are weak links according to the above functional definition. As a consequence, the program becomes more stable. Refactoring is a typical reconfiguration of a larger system, utilizing weak-link-induced stabilization. Another form of weak-link-related program stabilization is degeneracy. Degeneracy appears in the form of polymorphism of object-oriented systems (Myers, 2003).

As the extensive efforts for refactoring show, software systems are notoriously unstable and fragile. As an example of this, a simple typographical error usually halts a whole program behemoth. (For other amusing examples, just switch on your computer, and wait a little.) According to Lehman's second law, software systems tend to develop a high level of complexity "unless work is done to reduce it" (Lehman et al., 1998). Complexity is fueled by finite computational resources (Crutchfield, 1994). However, complexity here is not the complexity

[10]Examples of such refactoring steps are the introduction of smaller, more concise, single-purpose fragments, split into two subfunctions, etc.

which would automatically invoke stability and error tolerance. The complexity of software systems serves their extreme evolvability. As I mentioned above, the need for autonomous parts and extreme modularization are key points of software complexity. There is a rather recent trend which recognizes the parallel need for degenerate functions in larger programs. Degeneracy will serve the costs of its implementation and running by allowing the design of a safer and more stable computer program (Myers, 2003). We may observe that software design has smuggled tinkering into engineering in the form of refactoring and extreme programming (Beck, 1999; Brown et al., 1998; Fowler, 1999). However, this leads to the next section, where I return to engineering practices and summarize what we have learned so far about achieving stability in designed systems.

9.5 Engineers and Tinkerers: An Emerging Synthesis

In Sect. 3.6, I summarized Jacob's (1977) powerful view of evolution as a tinkerer who, in contrast to the engineer, does not optimize the system in advance, making a blueprint, but assembles interactions until they are able to work. Here I will show that the complexity of technical development has led to the convergence of engineering and tinkering. In other words (Sole et al., 2003a): "The fact that even engineers become tinkerers in large systems illustrates how complicated is the achievement of optimal structures once they reach some complexity level."

Indeed, engineered systems have long reached the point where our cognitive limits make the logical analysis of the system as a whole quite impossible in one mind alone. Since the extension of our biological 'cache memory', e.g., in the form of computer–human cyborgs, is not yet a reality, we have three options:

- We may employ exceptional people, who have extended cognitive abilities. This attributes a novel meaning to the previous remark that modern engineering is becoming an art. In this case the result may be exceptionally creative, even optimal, but its further development may be risky, requiring an original talent.
- We may break the design process into comprehensible parts and get used to the extensive application of motifs and modules (Alon, 2003). We may extensively develop fringe areas, pidgin formalization or design patterns, as described in the last section.

- Finally, we may also sacrifice some of the economy of the design and build in degenerate parts (Edelman and Gally, 2001), diversity and weak links to stabilize the system.

Highly optimized tolerance (HOT) (Carlson and Doyle, 2002; Csete and Doyle, 2002) should tend to become the self-organized optimal tolerance of the system itself including degeneracy and numerous weak links, rather than a carefully orchestrated human effort to achieve all this.[11] In nanotechnology and electronic chips, the construction of such complex systems is within reach (Edelman and Gally, 2001; Ottino, 2004). Indeed, recent advances in the self-assembly of complex micro-semiconductor designs (Zheng et al., 2004) signal a new era of network-driven engineering practice.

There is one more important consequence here. The innovation landscape of traditionally engineered systems is rough, in the sense that their 'innovation equilibrium' is highly punctuated. The different designs sit in the deep energy minimum of their purpose-optimized structure and further development becomes difficult. On the other hand, self-organizing, designable, degenerate systems "would serve unpredictable environmental conditions, where recognition of novelty is important and programmed planning is not possible" (Edelman and Gally, 2001). Similarly to the smoothing of the energy landscape of proteins (Sect. 5.3) or the diegetic landscape of dramas and novels (Sect. 9.2), weak links of engineered designs bridge the saddles of the innovation landscape (Tyre and Orlikowski, 1994) and allow a faster (and cheaper) development of novel design. Achieving both an improved safety and evolvability of our engineered systems in one act is worth the extra costs which the degenerate weak links may involve.

Here we end our fifth trip into Netland, in which we have surveyed some human-made networks. We have learned that ambiguity and degeneracy stabilize the meaning of our texts, the language net. The interconnected synchrony of multiple scale-free distributions may be an important feature of textual masterpieces, allowing them to induce better psychic relaxation and catharsis. The space around us is an extremely important element of our well-being, which has to be well designed with the fractal property and numerous weak links to stabi-

[11] An additional form of engineered diversity has emerged from studies of protein evolution. Highly evolved protein structures have higher 'designability', meaning that the same structure (design pattern) may accommodate more individual protein sequences (elementary solutions; Li et al., 1996; Tiana et al., 2004). The increased diversity of more designable systems also leads to the development of more weak links.

lize both ourselves and our community in towns. Finally, modularity, degeneracy and weak links are important to improve both the stability and evolvability of engineered systems. One of the most important treasures we have picked up are further examples to show that weak links help both stability *and* change in complex systems. This statement may seem rather contradictory as it stands, but it will become quite clear in the synthesis of Sect. 12.3.