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Lotka's distribution and distribution of co-author pairs' frequencies

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Abstract

The original Lotka's Law refers to single scientist distribution, i.e. the frequency of authors A_i with i publications per author is a function of i: $A_i = f(i)$. However, with increasing collaboration in science and in technology the study of the frequency of pairs or triples of co-authors is highly relevant. Starting with pair distribution well-ordered collaboration structures of co-author pairs will be presented, i.e. the frequency of co-author pairs N_{ij} between authors with i publications per author and authors with j publications per author is a function of i and j: $N_{ij} = f(i, j)$ using the normal count procedure for counting i or j. We have assumed that the distribution of co-author pairs' frequencies can be considered to be reflection of a social Gestalt and therefore can be described by the corresponding mathematical function based on well-known general characteristics of structures in interpersonal relations in social networks. We have shown that this model of social Gestalts can better explain the distribution of co-author pairs than by a simple bivariate function in analogy to Lotka's Law. This model is based on both the Gestalt theory and the old Chinese Yin/Yang theory.
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Keywords: Lotka's distribution; Collaboration; Co-authors; Gestalt theory; Yin–Yang-teaching

1. Introduction

1.1. First remarks

Since several decades, collaboration is increasing in science and in technology. Usually, the bibliometric method for the study of collaboration is the investigation of co-authorships (de B. Beaver, 2001; de Solla Price, 1963; Glänzel, 2002; Glänzel & de Lange, 1997; Glänzel & Schubert, 2004; Luukkonen, Persson, & Silvertse, 1992; Miquel & Okubo, 1994; Newman, 2001; Okubo, Miquel, Frigoletto, & Doré, 1992; Tijssen & Moed, 1989; Zitt, Bassecoulard, & Okubo, 2000).

The original Lotka's Law (Lotka, 1926) refers to single scientist distribution, i.e. the frequency of authors A_i with i publications per author is a function of i:

$$A_i = f(i) \quad (1)$$

However, with increasing collaboration in science and in technology the study of the frequency of pairs or triples of co-authors *is highly relevant*. Starting with pair distribution the frequency of co-author pairs N_{ij} between authors with i publications per author and authors with j publications per author is a function of i and j:

$$N_{ij} = f(i, j) \quad (2)$$

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Whereas regarding Lotka's Law single scientists *P* distribution (both in single authored and in multi-authored bibliographies) is of interest, in the future *pairs P*, *Q* distribution, *triples P*, *Q*, *R* distribution, etc., should be considered.

Starting with pair distribution, the following questions arise in the present paper:

- Is there any regularity for the distribution of co-author pairs' frequencies?
- If yes, can the distribution of co-author pairs be described by an extension of Lotka's Law or can this distribution be better described by a model of social Gestalts?

Regarding the last question, two theoretical distributions will be calculated and these distributions will be further specified and discussed in the next sections.

However, in Section 1 we only intend to visualize the two theoretical distributions in comparison with an empirical distribution.

1.2. Is there any regularity for the distribution of co-author pairs' frequencies?

For visualization, Lotka's distribution and co-authorship distribution of pairs of collaborators obtained from the journal *Science* are presented in Fig. 1. The articles from 1980 to 1998 of the journal *Science* were studied with 47,117 authors and the total sum of $N_{ij}=418{,}458$ co-author pairs (method for counting N_{ij}, cf. below).

Fig. 1 shows the distribution of the number of authors A_i with i publications per author (upper row) contrasted with the distribution of the number of co-author pairs N_{ij} between authors with i publications per author and authors with j publications per author (lower row). For clarity's sake and optimum visualization the presentation of data are restricted to authors with at most 10 articles i ($i=1, 2, \ldots, 10$) or j ($j=1, 2, \ldots, 10$) respectively.

The upper row reflects the Lotka's Law. In this row, the distribution of the number of authors A_i with i publications per author is given on the left, and on the right the corresponding double logarithmic presentation. A_i (or $\log A_i$ respectively) is plotted at the Y-axis and i (or $\log i$ respectively) is plotted at the X-axis.

In the lower row, the distribution of the number of co-author pairs N_{ij} is given on the left, and the corresponding triple logarithmic presentation on the right. The number of pairs N_{ij} (or $\log N_{ij}$ respectively) is plotted at the Z-axis, i (or $\log i$ respectively) is plotted at the X-axis and j (or $\log j$ respectively) is plotted at the Y-axis.

Fig. 1 has shown we can say yes to the first question that there is any regularity existing for the distribution of co-author pairs' frequencies.

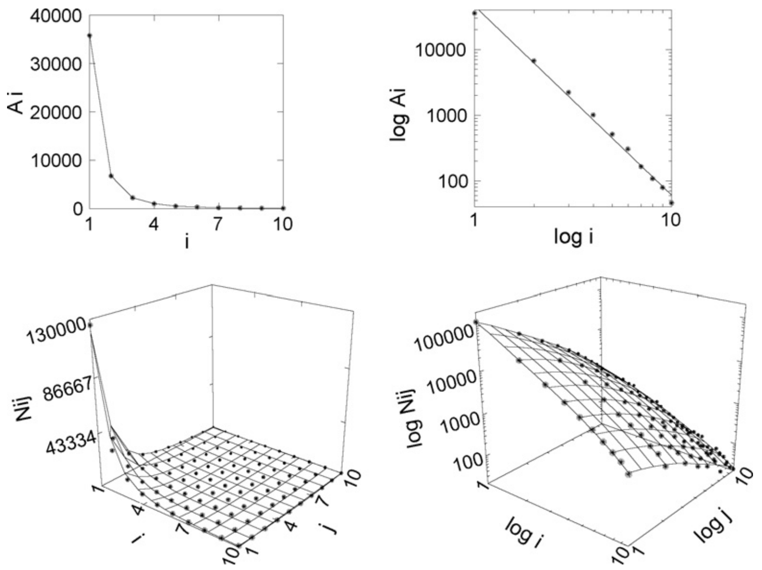

Fig. 1. Lotka's distribution [$A_i=f(i)$, upper row] in comparison with the distribution of co-author pairs' frequencies [$N_{ij}=f(i,j)$, lower row].

However, before considering the second question regarding the description of the distribution of co-author pairs' frequencies [$N_{ij} = f(i, j)$] information about the method of counting these co-author pairs is necessary.

Method for counting N_i and N_{ij} (in extended form, cf. Appendix A): Given is an artificial bibliography including eight papers (names of authors: A, B, . . .).

1.	A	4.	D, A, F	7.	H, G
2.	B	5.	C	8.	H, G, A
3.	D, E	6.	G, H		

The number of publications *i* (or *j* respectively) per author P (or Q respectively) is determined by resorting to the "normal count procedure". Each time the name of an author appears, it is counted (e.g. A three times: once in the first paper, and once each in the 4th and 8th papers).

Pairs P, Q are marked in the cells of the matrix under the condition of both the first authors P count (*i*) and the second authors Q count (*j*), i.e. the authors are ordered according to *i* or *j* respectively in both the row and the column (cf. Table 1).

Under the condition, the place of the authors in the by-line is not taken into consideration the symmetrical matrix is resulting. For example, the pair G, A is marked two times: once under the condition G count (*i*) and A count (*j*) and once under the condition A count (*i*) and G count (*j*).

In the symmetrical matrix, one can determine for each author P the number of his collaborators N_P. N_P is equal to the Degree Centrality in Social Network Analysis (SNA).

The matrix of N_{ij} (Table 2, derived from the symmetrical matrix) is the representation of the number of pairs N_{ij} with authors who have *i* publications per author, with authors who have *j* publications per author included in the bibliography.

For example, the pairs E, D and F, D in Table 1 are counted both as $N_{12} = 2$ and $N_{21} = 2$ in the matrix of N_{ij}.

Table 1
Symmetrical matrix of the pairs P, Q

i/*j*	P/Q	1				2	3			N_P
		B	C	E	F	D	A	G	H	
1	B									
	C									
	E					1				1
	F					1	1			2
2	D			1	1		1			3
3	A				1	1		1	1	4
	G						1		1	2
	H						1	1		2
SUM										14

Table 2
Matrix of N_{ij}

i/*j*	1	2	3	N_i	A_i	SUM
1	0	2	1	3	4	
2	2	0	1	3	1	
3	1	1	6	8	3	
N_j	3	3	8			14
A_j	4	1	3			8
SUM				14	8	

$N_i = \sum_j N_{ij}$ is the number of collaborators of all authors with *i* publications per author; $N_j = \sum_i N_{ij}$ is the number of collaborators of all authors with *j* publications per author; A_i is the number of authors with *i* publications per author; A_j is the number of authors with *j* publications per author.

1.3. Can the distribution of co-author pair's frequencies be better described by a model of social Gestalts than by the extension of Lotka's Law?

As mentioned above in Section 1 we only intend to visualize both the theoretical pattern derived from the extension of Lotka's Law and the theoretical pattern of social Gestalt in comparison with the empirical distribution obtained from the journal *Science*.

Fig. 2 shows the comparison of the empirical distribution of $\log N_{ij}$ with the two different distributions of theoretical values. The figures on the right are rotated by 90°.

The empirical distribution of the pairs' frequencies in *Science* (Fig. 2, second row) is rather equal to the theoretical distribution of social Gestalts (third row) but different from the other, i.e. from the pattern by the extension of Lotka's Law (first row).

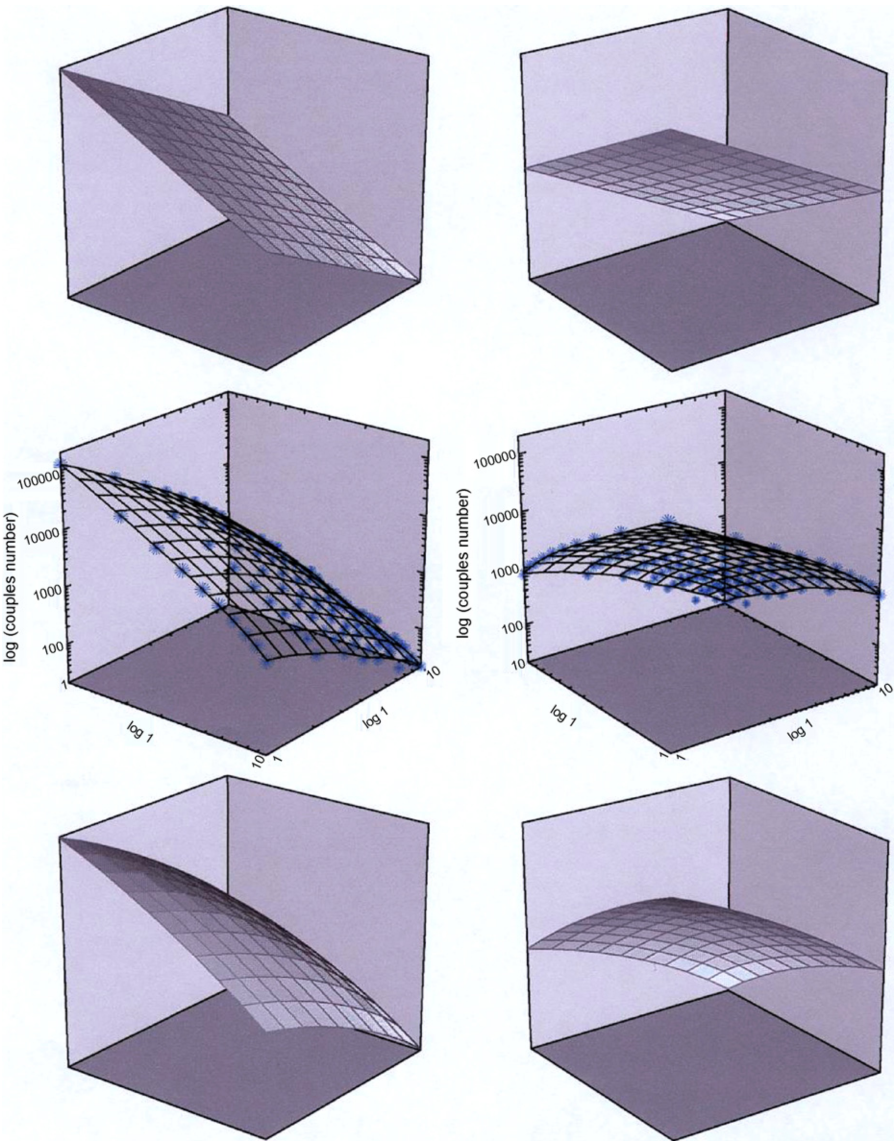

Fig. 2. Comparison of the empirical distribution of $\log N_{ij}$ (second row) of the journal Science with two different distributions of theoretical values (first and third rows). The figures on the right are rotated by 90°.

This is the first *proof for the assumption the distribution of the co-author pairs' frequencies N_{ij} can be considered to be a social Gestalt*. It is the key phrase of this paper stating a key result and it constitutes the principal method and the main point of the paper.

Both the extension of Lotka's Law and the meaning of Gestalt will be explained in the next sections followed by the mathematical function for the description of social Gestalts. This general theoretical function is valid for different kinds of social Gestalts. We will give the proof that the distribution of co-author pairs' frequencies is one example of them. Four journals are studied.

For thorough explanation of the theoretical and methodological background of the studies in this paper, in most of the sections or paragraphs reference is given to the corresponding information in the annex.

2. Theoretical bivariate distribution derived from the extension of Lotka's Law

Qin (1995) showed in her example, that the number of collaborators N_i is distributed in the same way as the total number of publications of all authors with i publications per author (T_i):

$$T_i = iA_i \tag{3}$$

This means, that the marginal sums N_i (or N_j respectively) should be distributed according to an inverse power function in line with Lotka's Law, however, with a different parameter:

$$N_i = \frac{\text{constant}}{i^a} \quad \left(\text{or } N_j = \frac{\text{constant}}{j^a} \text{ respectively}\right) \tag{4}$$

Because of the symmetry of the matrix, both the distributions of the marginal sums of the matrix are equal (row = column).

Assuming the condition, that the productivity of the authors has no social influence whatsoever, which author collaborates with which other author, the distribution of the number of pairs could be determined within the matrix solely on the basis of the marginal sums:

$$N'_{ij} = \frac{N_i N_j}{\sum_i N_i} \tag{5}$$

Under the condition the formula (4) is valid there could be a relationship in (5) with Lotka's Law and the distribution of the number of pairs could be formulated as follows:

$$N''_{ij} = \frac{\text{constant}}{(ij)^a} \tag{6}$$

and

$$\log N''_{ij} = \text{constant} + a(\log i + \log j) \tag{7}$$

This theoretical distribution (7) is shown in the first row of Fig. 2. While the double logarithmic presentation of Lotka's Law is a *straight line*, the triple logarithmic extension resembles a *plane surface* (extension of Lotka's Law).

3. Gestalt theory/psychology

3.1. General remarks

In the wake of a tangible change of paradigm in science occuring by the end of the 20th century, a number of holistic theories have emerged (e.g. Bohm, 1980; Laszlo, 1997; Prigogine & Stengers, 1984; Sheldrake, 1988; Stapp, 1993, etc., just to mention only a few of them) which are operating on the idea of holographic interacting entities in the world, with several of them also implying a *field concept*.

For example:

- magnetic field in physics,
- morphogenetic field of living organisms in evolutionary biology,
- psychological fields in psychology or sociology (Gestalts), etc.

According to Pribram (1997, p. 12) field concepts are being used as long as remote-field effects have to be explained.

The field concept says a force, which emanates from a field generates a balanced evenness among all the individual components in their totality.

In psychology the specialty "Gestalt" psychology had originated at the end of the 19th century with due consideration of psychological processes, with holistic organizational patterns playing a role that comprised man and the environment. These holistic entities are often designated as psychological fields. Their tendency towards a stable state of order is called conciseness (or "Prägnanz") tendency, it is a "*tendency towards a good Gestalt*". The stable final state is, if possible, built up in a simple, well-ordered, harmonic and uniform manner in line with definite rules. Several authors take the view that *these fields can be mathematically described*.

In the next paragraphs of this section:

- a rather new model of social Gestalts or behavioural fields is presented;
- as well as the illustration of the main idea with help of an example;
- beyond the main idea two further aspects of social Gestalts are explained as basis for the studies of co-author pairs' frequencies (varying shapes of social Gestalts and overlapping of social Gestalts).

3.2. Theoretical model of social "Gestalts" or behavioural fields

3.2.1. Overview

The rather new *theoretical model of social "Gestalts" or behavioural fields* (Kretschmer, 1999a, 2002) is intended to suggest that

* social interactions between a large number of individual persons;
* could be mirrored in the form of well-ordered three-dimensional Gestalts (fields) in dependence upon
* the characteristics of these individual persons (general characteristics in interpersonal relations in social networks: cf. Appendix E).

Examples (types) of social interactions are collaboration, friendships, marriages, etc., while examples (types) of characteristics of these individual persons are age, labor productivity, education, professional status, etc.

Because of the general validity of this model in social networks:

- social Gestalts can emerge independently on the types of characteristics of persons and interaction (illustration, cf. Appendix B);
- social Gestalts can emerge independently on the used statistical methods of interaction measurement (illustration, cf. Appendix C) or personality characteristics.

Thus, we intend to investigate whether the distribution of co-author pairs' frequencies can be considered to be a social Gestalt because co-authorships are the reflections of interactions and the scientific productivity can be considered as characteristic of persons. A large number of individual persons are studied with the help of bibliometric data.

Under the condition we can give the corresponding proof for the social Gestalt then distributions of co-author pairs' frequencies can be described by the mathematical function derived for the social Gestalts in social networks (Kretschmer, 2002 and Appendix F).

Whereas the principal points of the mathematical function will be explained in the next section in the present section, we illustrate the main idea of the theoretical model.

3.2.2. Illustration of the main idea of the theoretical model of social Gestalts in correspondence with Gestalt theory

- A force that emanates from the well-ordered pattern of the whole (social or behavioural Gestalt) acts on the individual components (individual persons) of this whole.

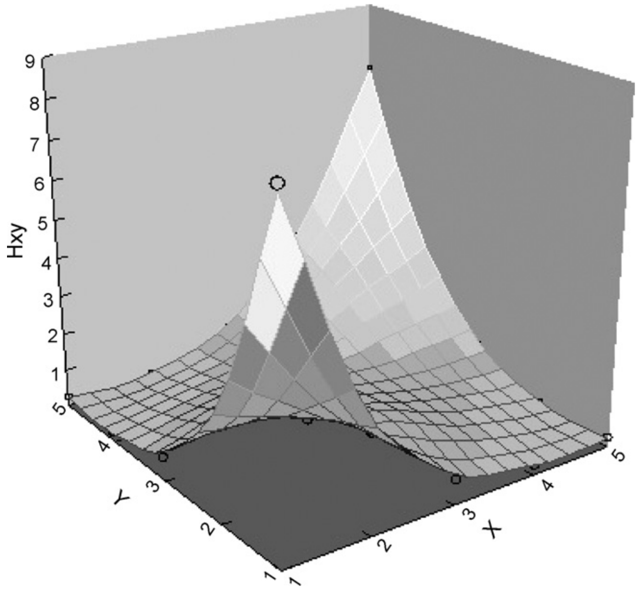

Fig. 3. Social Gestalt in the Timetables of Science (Hellemans & Bunch 1998) and in the Timetables of History (Grun, 1975)—*X*, *Y*: age (1: 21–30, 2: 31–40, 3: 41–50, 4: 51–60, 5: 61–70) and $Z = H_{XY}$: communication/collaboration.

- Even if this force fails to determine completely an individual component in terms of the predictability of this individual component:
  * this force, nevertheless, generates a statistically balanced evenness among all the individual components in their totality in the sense of a well-ordered pattern (according Gestalt theory: "*Tendency towards a good social Gestalt*");
  * suggesting that this Gestalt will become predictable within a very high margin of probability.

An example, most suitable for illustration of the main idea is shown in Fig. 3 although the shape of this special social Gestalt is very different from the shape of the distribution of co-author pairs' frequencies (Fig. 3 is a copy of a part of Fig. 1 on p. 450 in Kretschmer, Liang, & Kundra, 2001). Explanation about varying shapes of social Gestalts will be delivered in one of the next paragraphs of this section.

The idea of this example in Fig. 3 is connected especially with Liang Liming (Kretschmer et al., 2001). Whereas the ages of the scientists and artists which have been accomplished in collaboration/communication have to be plotted on the first (*X*) and second (*Y*) dimension the homophylic indices have to be plotted on the third (H_{XY}) dimension of the figure. The homophylic index was calculated as a *ratio between the observed to the statistically expected values* on the condition that the joint collaboration/communication was independent of the age (Homophylic index H_{XY}, cf. Appendix D).

There is a wide range of reasons for addressing *individual cases or components*, i.e. how is it explainable that especially the two scientists Otto Hahn and Lise Meitner, almost of identical age, had jointly succeeded in discovering protactinium and uranium, or why the 31-year-old Pascal and the 53-year-old de Fermat had jointly provided the foundations for the probability calculus. Every collaboration has its own history, even books had been written about many of them, for instance about the 25-year-old Watson and the 37-year-old Crick who jointly succeeded in determining the exact build-up of DNA. That means – as mentioned above – the force that emanates from the well-ordered pattern of the whole (social Gestalt) fails to determine completely an individual component part in terms of the predictability of this individual component.

However, in spite of the popular acclaim and the specific aspects relating to individual events *the force of the well-ordered Gestalt for the whole has demonstrably generated a statistically balanced evenness for the individual events*, indicating that a mathematically describable Gestalt can be envisioned (cf. Fig. 3).

In correspondence, we can expect the tendency towards a "Good Gestalt" is increasing with increasing number of individual components. That means large sample sizes should be preferred for studies. Furthermore, for the proof of social Gestalts an additional phenomenon of Gestalts should be taken into consideration originally related to morphogenetic fields or morphogenetic Gestalts: Overlapping or mixing of social Gestalts in analogy to overlapping of faces.

3.2.3. Overlapping of individual social Gestalts in analogy to overlapping of faces

In former studies (Kretschmer, 1999b) could be shown that the "Tendency towards a good gestalt" will enhance with the rising number of mixed social Gestalts (cf. Fig. 4, this figure is a copy of a part of Fig. 3 on p. 511 in Kretschmer, 1999a).

This phenomenon is in correspondence with superimpositions or overlappings of facial contours which have been made in a number of cases. Fischer, reported in 1997 that Sir Francis Galton, the English natural scientist and anthropologist had tried already in 1878 to identify the typical countenance of a law-breaker.

In each of these experiments it was surprisingly revealed – independently of who had performed them – that the result of the superimposedly mixed or average faces was more attractive than the individual ones and that these mixed faces became the more attractive, the greater was the number of overlappings. The "more attractive" faces were considered more well-ordered and harmonic and generally more proportional.

This is in correspondence with Gestalt theory, i.e. with the "*tendency towards a good Gestalt*". Although the force that emanates from the well-ordered Gestalt of a face fails to determine completely an individual face in terms of the predictability of this individual face this force, nevertheless, generates a statistically balanced evenness among all the individual faces in their totality. Thus, in empirical studies with increasing number of individual social Gestalts the mixed pattern is more even than the individuals.

That tendency is independent of the kind of Gestalts, morphogenetic (faces) or psychological or social or others.

Therefore, it is tested in one of the next sections whether the empirical distribution of the co-author pairs' frequencies of the mixed four distributions is of higher similarity to the corresponding well-ordered Gestalt than the single distributions per se.

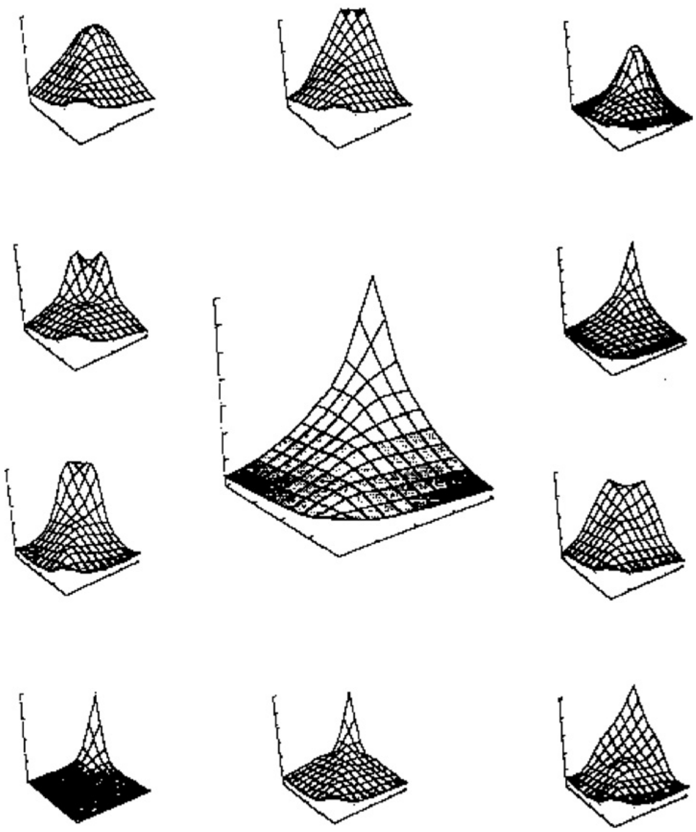

Fig. 4. Social Gestalts in the co-authorship networks of medicine; *X*, *Y*: productivity of scientists and *Z*: relative frequency of co-authorships. The mixed or average pattern in the middle is more even than the individual patterns around (this figure is a copy of a part of Fig. 3 on p. 511 in Kretschmer, 1999a).

However, what does it mean that the shapes of the social Gestalts in Fig. 3 and in the middle of Fig. 4 are looking different from each other?

3.2.4. Shapes of social Gestalts

Based on the influence of the changes of men and environment these social Gestalts can change the shape resulting in a diversity of social Gestalts. Explanation will be given in the next section. These many Gestalts are classified into prototypes in the sense of well-ordered patterns or "Good Gestalts" (Fig. 5). The Gestalt in Fig. 3 is similar to the prototype in the middle of Fig. 5 and the mixed Gestalt in Fig. 4 is similar to the right prototype.

An example for changing the Gestalt of co-authorship networks from one of the prototypes to another one – based on the influence of the changing research conditions – could be shown by Kretschmer et al. (2001) when studying the co-authorship network of Indian medicine in the course of about 30 years, Fig. 6. Whereas the left pattern in the third row of Fig. 6 is similar to the left prototype in the second row of Fig. 5: the right pattern in the third row of Fig. 6 is similar to the prototype in the middle of Fig. 5, i.e. there is a change of the shape of Gestalts from one of the prototypes to another one.

Additionally – and independent from considering the change of the shapes – turning the distribution of co-author pairs (Fig. 1, lower row on the left) around 90° we can find a shape of Gestalt similar to the left prototype in the second row of Fig. 5.

It is interesting to study in future whether we can find any change of the Gestalts of the distribution of co-author pairs' frequencies during several decades.

Additionally, the shape can depend on the used statistical methods of interaction measurement (illustration, cf. Appendix C), on the measurement of personality characteristics or on the methods of presentation as follows: a social Gestalt (field) is existing in the reality independent on our scientific methods we are using for visualization of this Gestalt. The results of different kinds of methods are different kinds of reflections of the real Gestalt. For example, different kinds of mirrors can reflect our man body in different shapes, even rather distorted.

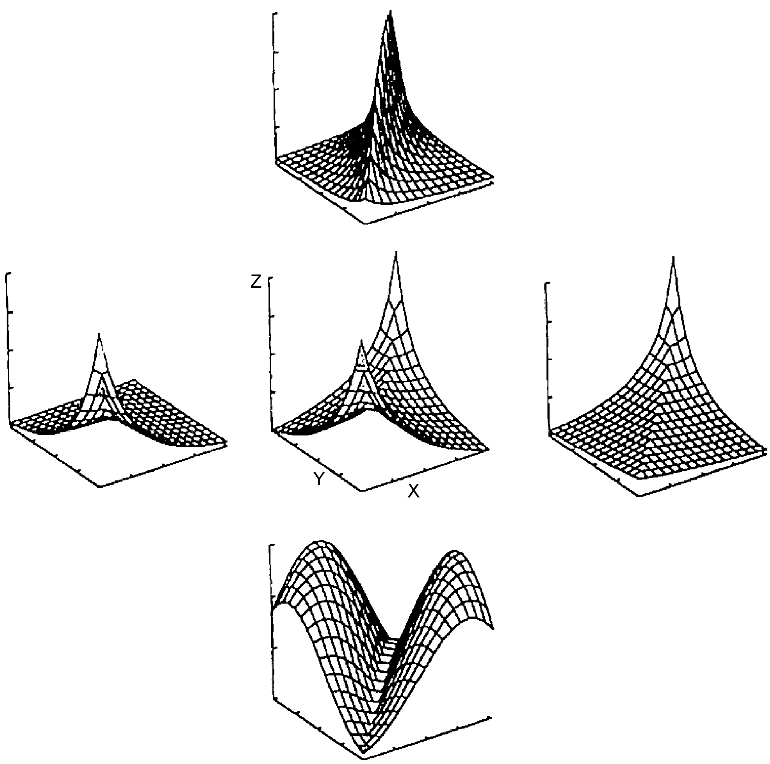

Fig. 5. Prototypes of social Gestalts.

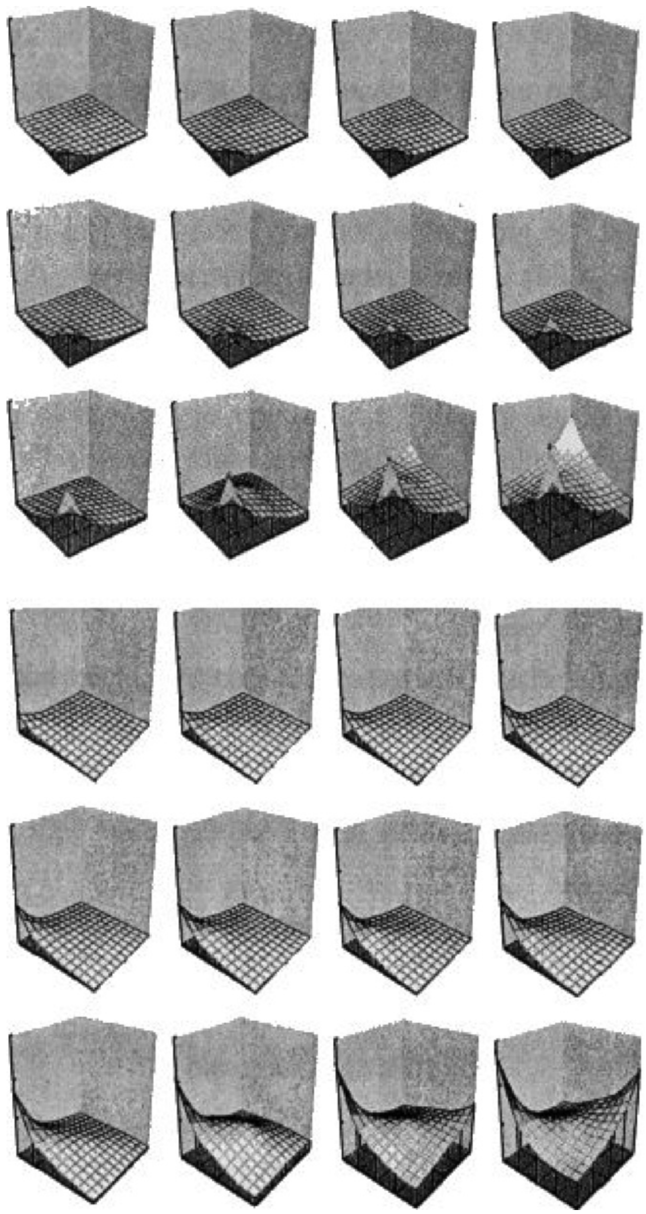

Fig. 6. Change of the shapes dependent on the changing environment and men (Indian medicine during 30 years). The lower half of the figure (three rows) is rotate by 90°.

4. Mathematical function for the description of social Gestalts (derivation in detail: cf. Appendices E and F)

4.1. Remarks

The development of the mathematical function is based on both the old Chinese Yin/Yang theory and well-known *general characteristics* of structures in interpersonal relations in social networks (Kretschmer, 1999a, 2002 and Appendix E). These general characteristics of social structures are already partly identifiable in groups of higher vertebrates.

One of these general characteristics of structures is well-known as proverb: “Birds of a feather flock together”. It means in the example of co-authorship networks there are a higher number of co-author pairs N_{ij} than expected with similar productivity of the co-authors ($i \sim j$).

We have mentioned earlier in (2):

$$N_{ij} = f(i, j)$$

N_{ij} is plotted at the Z-axis, i at the X-axis and j at the Y-axis.

In the general case, we can say regarding social Gestalts:

$$Z = F(X, Y) \tag{8}$$

Z is value of social interactions, and X and Y are values of different persons of a special personality characteristic.

However, there is also another general characteristic of structures in interpersonal relations: "Opposites attract".

Both opposing proverbs above give rise to reflect on the notion of complementarity (e.g. also particle/wave by Niels Bohr).

The modern notion of complementarity had existed already in a clear-cut manner in old Chinese thought, in the Yin/Yang Theory.

Yin and Yang have to be seen as polar forces, as complementary tendencies interacting dynamically with each other, so that the entire system is kept flexible and open to change.

For example, in social networks Yin can be considered as dissimilarity (A) and Yang as similarity ($A_{\mathrm{COMPLEMENT}}$) of persons in social networks.

4.2. Theoretical two-dimensional patterns

For demonstration how the two polar forces are interacting as complementary tendencies dynamically with each other, so that the entire system is kept flexible and open to change let us have a view at the next figure (Fig. 7). The patterns of this figure are produced by a systematic variation of the two parameters (α and β) of the following function (9) (explanation for selecting this kind of function can be found in Appendix F).

This function is the product of both the power function of the dissimilarity and the power function of the complement (similarity):

$$Z^* = f(X, Y) = \text{constant}\,(A+1)^{\alpha}(A_{\mathrm{COMPLEMENT}}+1)^{\beta} \tag{9}$$

$$\text{Dissimilarity}: \quad A = |X - Y| \tag{10}$$

$$\text{Similarity}: \quad A_{\mathrm{COMPLEMENT}} = |X - Y|_{\max} + |X - Y|_{\min} - |X - Y| \tag{11}$$

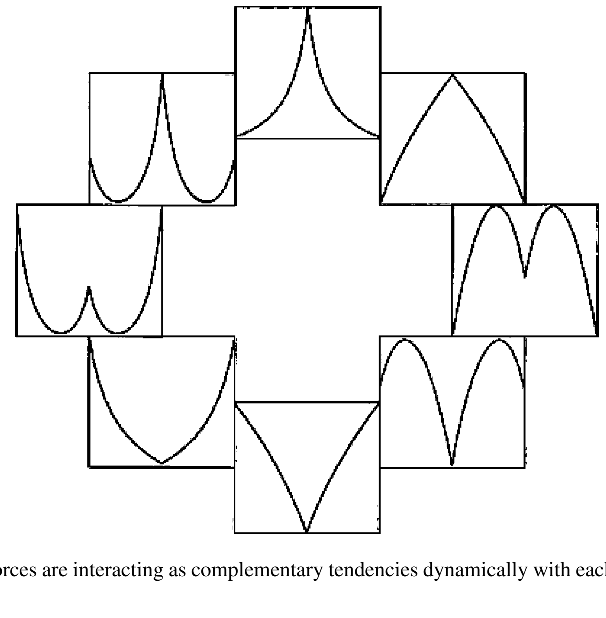

Fig. 7. Presentation how two polar forces are interacting as complementary tendencies dynamically with each other on one dimension according to the function (9).

In every box of Fig. 7 the difference $|X-Y|$ is always the abscissa and Z^* the ordinate axis. In the middle of the abscissa is $X-Y=0$. The relationships of the two parameters to each other determine the expressions of Yin and Yang in each of the patterns.

Fig. 7 shows only eight patterns as typical examples. However, according to Chinese philosophy, Yin and Yang are the opposite poles of a single whole. There is not an isolated exclusive Yin, or only a Yang. All transitions occur with a direct and uninterrupted sequence. The natural order is secured by the dynamic equilibrium between Yin and Yang. That means, theoretically an infinite number of patterns should have been produced in Fig. 7 for presentation of all of the possible patterns.

For explanation, we intend to characterise four types of similar patterns only:

- the Yang pattern (upper pattern),
- the Yin-in-Yang pattern (left pattern),
- the Yin pattern (pattern below), and
- the Yang-in-Yin pattern (right pattern).

While in the upper pattern Yang is more likely to be in the foreground (birds of the feather flock together), the pattern below reveals that Yin is more likely to be accentuated (Opposites attract).

Starting from the left side of the upper pattern in the direction of the pattern below from pattern to pattern Yang has retracted itself in favour of Yin.

Vice versa, starting from the right side of the pattern below in the direction of the upper pattern from pattern to pattern Yin has retracted itself in favour of Yang.

4.3. Empirical two-dimensional patterns

Thirty-two empirical patterns could be found matching rather all of these theoretical patterns in Fig. 7 (Kretschmer, 1999a, Fig. 3, p. 511). Patterns of co-authorship networks in institutions are similar to the patterns of the lower half in Fig. 7 (“Opposites attract”) and patterns of co-authorship networks in “Invisible Colleges” are similar to the patterns of the upper half in Fig. 7 (“Birds of a feather flock together”).

4.4. Theoretical three-dimensional patterns

Because of the existing general structures in social networks, we have extended our visualization up to two different Yin/Yang pairs.

In the first pair, Yin was considered as dissimilarity (A) and Yang as similarity ($A_{\mathrm{COMPLEMENT}}$).

But in the second pair, Yin can be considered as low mixed value (B) and Yang as high mixed value ($B_{\mathrm{COMPLEMENT}}$) of a special personality characteristic.

In analogy to the first Yin/Yang pair, we define:

$$B = X + Y \tag{12}$$

and

$$B_{\mathrm{COMPLEMENT}} = (X+Y)_{\max} + (X+Y)_{\min} - (X+Y) \tag{13}$$

$$Z^{**} = (B+1)^{\gamma}(B_{\mathrm{COMPLEMENT}}+1)^{\delta} \tag{14}$$

We have to mention there is a difference of the patterns resulting from Z^* in Fig. 7 and the patterns resulting from Z^{**}.

Because of the absolute values $A=|X-Y|$, symmetrical patterns are shown in Fig. 7 but non-symmetrical patterns emerge according to the function Z^{**}. These non-symmetrical patterns are looking like the patterns in Fig. 7 under the condition the left parts of each of these patterns are deleted.

One of the well-known general characteristics of structures in interpersonal relations in social networks is called “edge effect” (U-curve) and the meaning is explained in Appendix E. While the U-curve is equal to a Yin-in-Yang

Table 3
For each of the prototypes: expression of Yin/Yang in the first pair combined with expression of Yin/Yang in the second pair

Prototype	First pair	Second pair
Left	Yang	Yin
Right	Yang	Yang
Middle	Yang	Yin-in-Yang
Upper	Yang	Yang-in-Yin
Below	Yin	Yang-in-Yin

pattern the reversed U-curve is equal to a Yang-in-Yin pattern. We have explained an example of the edge effect, related to the main diagonal of the matrix Z_{XY} in Appendix F.3.

It is conclusively consistent with all above considerations to seek a simple mathematical function (conciseness principle) for the description of a social Gestalt (Kretschmer, 2002). Thus, we have combined function Z^* and function Z^{**}:

$$Z = f(X, Y) = \text{constant}\, Z^* Z^{**} \tag{15}$$

$$Z = \text{constant}\,(A + 1)^{\alpha}(A_{\text{COMPLEMENT}} + 1)^{\beta}(B + 1)^{\gamma}(B_{\text{COMPLEMENT}} + 1)^{\delta} \tag{16}$$

The diversity of behavioural Gestalts is expressed by the variation of the four parameters of this function, with the diversity being dependent upon the conditions influencing these Gestalts (e.g. men and environment or statistical methods of interaction measurement, etc.). Prototypes of these social Gestalts are already presented in Fig. 5.

The expressions of Yin or Yang in both of the Yin/Yang pairs of each of the prototypes are presented in Table 3.

4.5. Empirical three-dimensional patterns

The social Gestalts in co-authorship networks, which are widely spread over the entire world, are obviously real objects that owe their shape to the balancing interaction of forces, namely to the dynamic equilibriums interacting between Yin and Yang in the sense of ancient Chinese philosophy. Thus, several empirical social Gestalts matching the five prototypes were taken out and presented in Kretschmer (2002).

5. Hypotheses

We have shown the derivation of a function with four parameters and one constant for describing social or behavioural Gestalts in general (16).

For definition of hypotheses regarding the example of co-author pairs' frequencies N_{ij}, we have to specify the variables for the study of this kind of social Gestalts.

There is a conjecture by de Solla Price (1963), physicist and science historian, that the logarithm of the number of publications is of a higher degree of importance than the number of publications per se.

Thus, using the logarithm of the number of publications ($\log i$ or $\log j$ respectively) as personal characteristic "productivity", we define:

$$X = \log i \tag{17}$$

$$Y = \log j \tag{18}$$

$$A = |\log i - \log j| \tag{19}$$

$$B = \log i + \log j \tag{20}$$

Thus:

$$A_{\min} = |X - Y|_{\min} = |\log 1 - \log 1| = 0 \tag{21}$$

$$A_{\max} = |X - Y|_{\max} = |(\log i)_{\max} - \log 1| = |\log 1 - (\log j)_{\max}| = (\log i)_{\max} = (\log j)_{\max} \tag{22}$$

$$B_{\min} = (X + Y)_{\min} = \log 1 + \log 1 = 0 \tag{23}$$

$$B_{max} = (X + Y)_{max} = (\log i)_{max} + (\log j)_{max} = 2(\log i)_{max} = 2(\log j)_{max} \quad (24)$$

Let us lay down a specific value for the maximum possible number of publications i (or j respectively) of an author as standard for such studies, which does not vary depending upon the given sample. It is assumed that the maximum possible number of publications of an author is equal to 1000, i.e.

$$A_{max} = \log 1000 = 3 \quad (25)$$

$$B_{max} = 2A_{max} = 6 \quad (26)$$

Following:

$$A_{COMPLEMENT} = 3 - |\log i - \log j| \quad (27)$$

$$B_{COMPLEMENT} = 6 - (\log i + \log j) \quad (28)$$

The theoretical mathematical function for describing the social Gestalts of the distribution of co-author pairs' frequencies is resulting:

$$N_{ij} = \text{constant}\,(|\log i - \log j| + 1)^{\alpha}(4 - |\log i - \log j|)^{\beta}(\log i + \log j + 1)^{\gamma}(7 - \log i - \log j)^{\delta} \quad (29)$$

Based on this function, three hypotheses are tested in this paper:

1. The distribution of the frequencies of co-author pairs N_{ij} can be considered to be the reflection of a social Gestalt with $X = \log i$, $Y = \log j$, and $Z = N_{ij}$ representing a prototype with the expression of Yang in the first Yin/Yang pair and the expression of Yin in the second. The first proof of this assumption was already given by visualization in Section 1. The second proof of this assumption will follow by regression analysis.
2. In relation to the phenomenon of overlapping of facial contours, we expect the "Tendency towards a good gestalt" will enhance with mixing of the four distributions obtained from four different journals.
3. The distribution of co-author pairs' frequencies N_{ij} can be better described by a model of social Gestalts than by an extension of Lotka's Law.

6. Data

Articles of the following journals are studied from 1980–1998:

- of the journal *Science* with 47,117 authors and the total sum of $N_{ij} = 418{,}458$ co-author pairs;
- of the journal *Nature* with 52,838 authors and the total sum of $N_{ij} = 581{,}698$ co-author pairs;
- of the journal *Proc Natl Acad Sci USA* with 79,877 authors and the total sum of $N_{ij} = 704{,}032$ co-author pairs;
- of the journal *Phys Rev B Condensed Matter* with 46,232 authors and the total sum of $N_{ij} = 544{,}006$ co-author pairs.

7. Methods and results

7.1. Remarks

The methods for counting N_i and N_{ij} are already presented in Section 1 as well as in Appendix A in extended form.

The first proof for the assumption that the distribution of co-author pairs' frequencies can be considered to be a social Gestalt is given by visualization in Fig. 2 of Section 1. In this connection, the first proof is also given for the assumption the distribution of co-author pair's frequencies can be better described by a model of social Gestalts than by a simple bivariate function in analogy to Lotka's Law (extension of Lotka's law).

7.2. Second proof for the assumption that the distribution of co-author pairs' frequencies can be considered to be a social Gestalt

This second proof has to be given by regression analysis.

Table 4
Regression analysis: distribution of the co-author pairs N_{ij}

	Science	*Nature*	*PNAS*	*Phys Rev B Condensed Matter*
Cut 10, $n = 55$	$R = 0.998$, $F = 3317.5$	$R = 0.997$, $F = 2105.3$	$R = 0.999$, $F = 7346.8$	$R = 0.999$, $F = 4202.29$
Cut 15, $n = 120$	$R = 0.995$, $F = 2881.7$	$R = 0.992$, $F = 1757.7$	$R = 0.997$, $F = 4767.5$	$R = 0.999$, $F = 6559.8$
Cut 31, $n = 496$	$R = 0.980$, $F = 1668.0$	$R = 0.972$, $F = 1427.5$	$R = 0.976$, $F = 2256.97$	$R = 0.988$, $F = 5161.9$

Note: R—correlation coefficient; F—F-ratio; n—values (n corresponds to the half matrix only, plus main diagonal).

Fig. 2 has shown the distribution of the frequency of co-author pairs N_{ij}. For clarity's sake and optimum visualization the presentation was restricted to authors with at most ten articles i ($i = 1, 2, \ldots, 10$) or j ($j = 1, 2, \ldots, 10$), respectively. We want to continue this procedure also in using regression analysis in the following three steps.

The empirical distributions of N_{ij} are considered

- under the condition (Cut 10) the data were cut off after $i = 10$;
- under the condition (Cut 15) of cut off after $i = 15$ (in the average about 99% of the authors are included);
- under the condition (Cut 31) of cut off after $i = 31$ (only a very few of the highest productive authors are not included).

Under the condition of logarithmic presentation after regression analysis, the correlations R between theoretical and empirical values of $\log N_{ij}$ and the F-ratios could be found for the four journals (Table 4).

In all of the four journals, both the correlations and the F-ratios are decreasing from Cut 10 in the direction to Cut 31. We assume this decrease is caused by decreasing frequencies of pairs N_{ij} with increasing i and j. As mentioned above there are two options for testing this assumption:

- In correspondence with the main idea of the theoretical model of social Gestalts (cf. Section 3.2.2), we can expect the tendency towards a "Good Gestalt" is increasing with increasing number of individual components. That means larger sample sizes with higher co-author pairs' frequencies should be preferred for studies.
- Furthermore, for the proof of social Gestalts an additional phenomenon of Gestalts should be taken into consideration originally related to morphogenetic fields or morphogenetic Gestalts (cf. Section 3.2.3). That means the empirical distribution of the co-author pairs' frequencies of the mixed four distributions should be of higher similarity to the corresponding well-ordered Gestalt than the single distributions.

We are using the second option in our empirical test because of difficulties to find many journals with higher co-author pairs' frequencies than the studied four journals.

7.3. Overlapping or mixing of four distributions of co-author pairs' frequencies obtained from four different journals

In analogy to the method of overlapping faces, the four matrices of co-author pairs' frequencies N_{ij} (cf. Table 2 in Section 1) are the basis for the method of mixing the distributions.

The mix M_{ij} has to be calculated for each of the N_{ijk} with k ($k = 1, 2, \ldots, 4$) for the journals ($k = 1$ for *Science*, $k = 2$ for *Nature*, $k = 3$ for *Proc Natl Acad Sci USA*, $k = 4$ for *Phys Rev B Condensed*:

$$M_{ij} = \sum_k N_{ijk} \tag{30}$$

Results of the mixed co-author pairs' frequencies M_{ij} are resulting:

- for Cut 10, $n = 55$: $R = 1.000$, $F = 16{,}145.8$;
- for Cut 15, $n = 120$: $R = 0.999$, $F = 13{,}431.0$;
- for Cut 31, $n = 496$: $R = 0.994$, $F = 9555.3$.

All of these results show for the mixed distribution, both higher correlation coefficients between empirical and theoretical values and higher F-ratios than for the single distributions separately.

The distribution of the mixed co-author pairs' frequencies M_{ij} obtained from the four single distributions (Cut 31) shows the high evenness of the mixed pattern in Fig. 8 ("Tendency towards a good Gestalt"). In both Fig. 8a and b

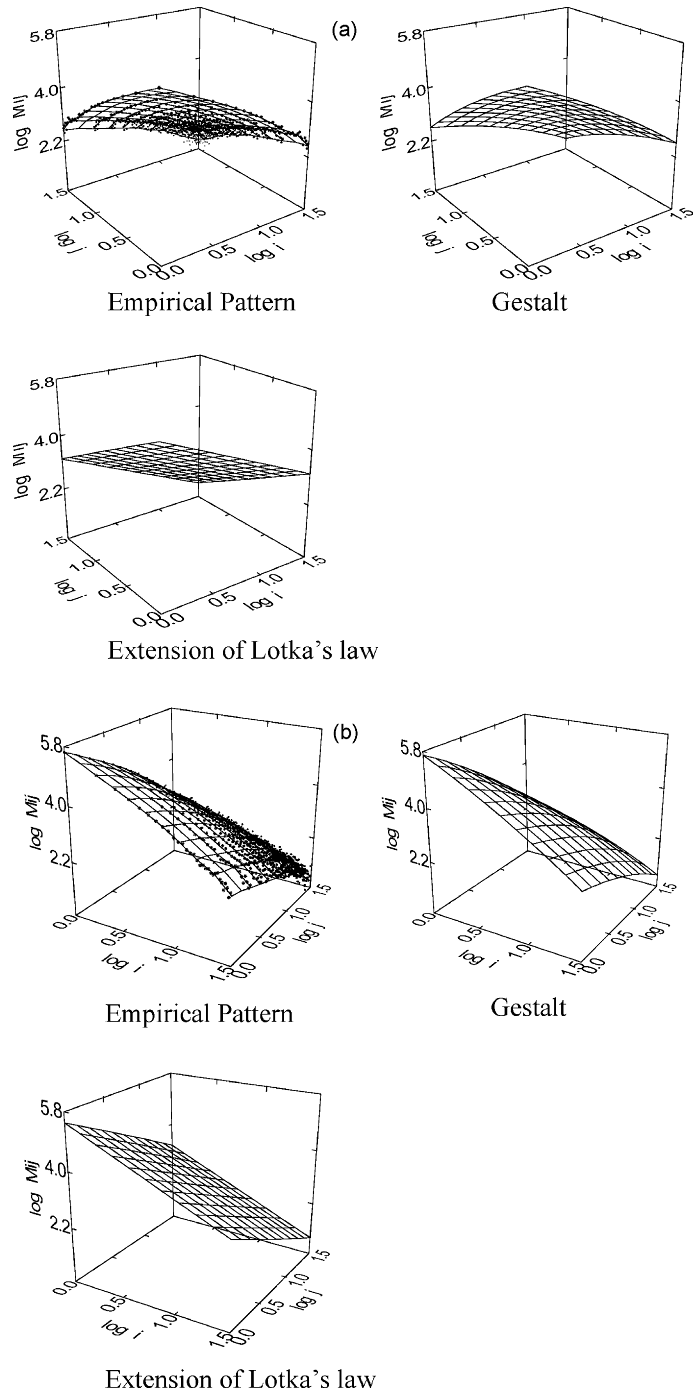

Fig. 8. (a and b) Distribution of the mixed co-author pairs' frequencies M_{ij} obtained from the four single distributions (Cut 31). (b) Rotated by 90°. In both (a and b): triple logarithmic presentation of the empirical pattern (first row, left) in comparison with Gestalt (first row, right) and extension of Lotka's Law (second row).

(Fig. 8b is rotated by 90°), the triple logarithmic presentation of the empirical pattern (first row, left) can be compared with Gestalt (first row, right) and the "extension of Lotka's Law" (second row). In analogy to Fig. 2, this is a proof for the assumption that a model of social Gestalts can better describe the distribution of co-author pair's frequencies than by extension of Lotka's Law.

7.4. Second proof for the assumption that the distribution of co-author pair's frequencies can be better described by a model of social Gestalts than by an extension of Lotka's Law

The first proof was given by visualizations in Figs. 2 and 8. Fostering the proof for the assumption that a model of social gestalts can better describe the distribution of co-author pair's frequencies than by extension of Lotka's Law we are using another method additionally.

We consider the distribution of the ratios between the empirical M_{ij} values of the mixed bibliographies to the theoretical values M''_{ij} [In analogy to (6): $M''_{ij} = \text{constant}/(ij)^a$], cf. Fig. 9.

Under the condition, the distribution of the co-author pairs can be approximated by the extension of Lotka's Law we should expect the ratios between the empirical values to the theoretical values are rather similar to 1.

However in opposite, a social Gestalt emerged that can be described by the model. The above-mentioned social regularity: "Birds of a feather flock together" is visible (left and right pattern) as well as one of the other regularities, i.e. the reversed U-curve (middle pattern).

"Birds of a feather flock together" means, the frequencies of co-author pairs with the same frequency of papers are higher than expected by the theoretical values (extension of Lotka's Law) and is decreasing with increasing differences between the productivities of authors. The relative frequencies of co-author pairs (ratio) with the same number of papers ($i = j$) can be found in the main diagonal. The main diagonal is starting in front of the left and the right patterns.

In correspondence with this result, we could find in each of the studied cases above (Cut 10, Cut 15, Cut 31 of all of the four journals and of the mixed distribution), that the correlations R between the empirical values and the theoretical values of Gestalts are higher than between the empirical values and the theoretical values of the extension of Lotka's Law.

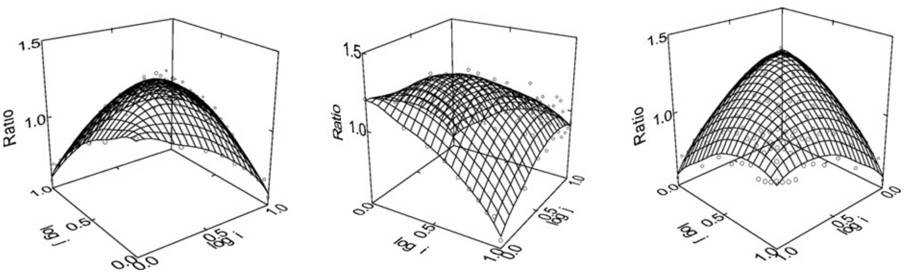

Fig. 9. Ratio between empirical M_{ij} values of the mixed bibliographies to the theoretical values M''_{ij} obtained by the extension of Lotka's Law. $R = 0.967$ after regression analysis with Gestalt (Cut 10). The ratios are plotted at the Z-axis, $\log i$ is plotted at the X-axis and $\log j$ is plotted at the Y-axis. The middle pattern is rotated by 90° and the right rotate the middle pattern.

8. Discussion and proposal for future investigations

The original Lotka's Law refers to the distribution of author frequencies. However, with increasing collaboration in science and in technology the study of the frequency of pairs or triples of co-authors is highly relevant. Kretschmer and Kretschmer have shown that there are regularities existing for the well-ordered distribution of co-author pairs' frequencies (Fig. 1). As far as Kretschmers' know, there is not any other presentation of this kind of pattern available in the former literature except the corresponding contributions of these authors in conference proceedings or in the grey literature (Kretschmer, 2001; Kretschmer & Kretschmer, 2004, 2006a, 2006b, 2007a, 2007b).

Recently Kretschmer (1999a, 2002) has created a theoretical model for social Gestalts valid for social networks in general. This model is based on both the Gestalt (field) theory and the old Chinese Yin/Yang theory. Yin and

Yang are the opposite poles of a single whole. They are complementary tendencies interacting dynamically with each other, so that the whole system is open to change. Gestalts in social networks owe their shape and change of their shape to the balancing interaction of these forces. All transitions occur with an uninterrupted sequence producing an infinite number of shapes. The model includes two different Yin/Yang pairs. These pairs are in correspondence with well-known general characteristics of structures in interpersonal relations in social networks. Typical shapes of special expressions of Yin/Yang in the first pair combined with expressions of Yin/Yang in the second are selected and shown in Fig. 5 (prototypes). The theoretical shapes can be produced by the mathematical function for the description of social Gestalts.

Empirical findings have shown social Gestalts are existing matching the different theoretical prototypes.

We have assumed that the distribution of co-author pairs' frequencies can be considered to be an example of social Gestalts and therefore can be described by the corresponding mathematical function.

The first hypothesis says the distribution of the observed frequencies of co-author pairs can be considered to be the reflection of a social Gestalt representing a prototype with the expression of Yang in the first Yin/Yang pair and the expression of Yin in the second. We have verified this hypothesis both by visualization and by regression analysis. However, we assume this expression of Yin in the second pair is strongly influenced by the Lotka's distribution, i.e. it is influenced by the decreasing frequency of authors A_i (or A_j respectively) with increasing i (or j) publications per author. Although this influence exists, it fails to determine completely the distribution of the frequencies of co-author pairs as shown in the empirical studies of the four journals (cf. Figs. 2 and 8). This is one of the verifications of the third hypothesis. In correspondence, the distribution of the ratios between empirical to theoretical values (extension of Lotka's Law) can be considered as social Gestalt (Fig. 9).

Regarding the second hypothesis, the overlapping of the four distributions of co-author pairs' frequencies obtained from four different journals has shown a very high evenness of the mixed pattern in Fig. 8, i.e. the "tendency towards a good Gestalt" is enhanced in relation to the separate single distributions. Thus, using mixed distributions, verifications of both the first and the second hypotheses are becoming easier. These studies have to be continued with other journals in future.

Using observed frequencies but a classification of the data i and j is done (cf. Appendix A), changing shapes during a longer time period can be made easier visible than without any classification. An example for changing the shape of the Gestalt was shown with help of the co-authorship network of Indian medicine in the course of about 30 years (cf. Fig. 6). It is interesting to study in future whether we can find any other changes of the Gestalts of the distribution of co-author pairs' frequencies during several decades.

Changing the shape of pattern with the expression of Yang in the first Yin/Yang pair and the expression of Yin in the second can also be caused by using another method of interaction measurement (for example, relative frequencies instead of observed).

The *famous Lotka*'*s Law* discovered in 1926 keeps on fascinating scientists from all fields. Lotka's Law *based on single scientists P counting* is valid for:

- single authored bibliographies, and
- *under the condition of normal count procedure*, also for multi-authored bibliographies. Both the theoretical and the empirical distributions are well-ordered as known from the single authored bibliographies.

There are several other methods also possible for counting single scientists, pairs, triples, etc.

For example, *weighted* (*or fractional*) *counting*, in which each co-author of m co-authors per paper receives 1/*m*th credit.

While normal count frequency distributions are well-ordered, fractional frequency distributions of, for example, authors with a certain (fractional) number of papers are very irregular (Egghe & Ravichandra Rao, 2002; Ravichandra Rao, Sahoo, & Egghe, 2003; Rousseau, 1992). Therefore, in future investigations are of interest whether social Gestalts also emerge based on fractional frequency distributions.

We have selected in this paper a special basic research question of collaboration studies, in comparison with Lotka's Law and we assume that possibly this result is valid in many journals.

Beyond these well-ordered distributions of co-author pairs' frequencies, long lists of other phenomena are existing regarding collaboration in science because co-authorship depends on different aspects, for example on field, gender, time, age, social, economic, political conditions, etc. Maybe in future studies we can find changing shapes of Gestalts depending on these various aspects.

Acknowledgments

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Appendix A. Methods for counting N_i and N_{ij} (extended version)

Different versions of counting pairs P, Q are possible. Two of them will be presented below.

Given is an artificial bibliography including eight papers (partly represented, names of authors A, B, . . .).

1. A
2. B
3. D, E
4. D, A, F
5. C
6. G, H
7. H, G
8. H, G, A

The number of publications *i* per author P is determined by resorting to the “normal count procedure”. Each time the name of an author appears, it is counted (e.g. A three times: once in the first paper, and once each in the 4th and 8th papers).

First version:

Pairs P, Q are counted analog to single authors P in Lotka’s Law. The number of publications n_c per pair P, Q is determined (D, E one times; D, A one times; D, F one times; A, F one times; G, H one times; H, A one times; G, A one times; H, G two times).

Second version:

Pairs P, Q are counted under the condition of both the first authors P count (*i*) and the second authors Q count (*j*), i.e. the authors are ordered according to *i* or *j* respectively (cf. Table 5).

In the present paper the symmetrical form of matrix 1 will be studied, see Table 6.

In the symmetrical matrix, one can determine for each author P the number of his collaborators N_P as well as the total sum of his relationships through co-authorships C_P.

The number of collaborators N_P is the number of pairs assigned to the author P in the corresponding row of the matrix. The number of relationships through co-authorships can differ between the pairs.

For example, the author P = H has two collaborators ($N_H = 2$), namely Q_1 = A and Q_2 = G. While the author H has one relationship with the collaborator A through co-authorships, there are three relationships with the collaborator G.

Table 5
Matrix 1

i/*j*	1				2	3		
	B	C	E	F	D	A	G	H
1								
B								
C								
E								
F								
2								
D			1	1		1		
3								
A				1				
G						1		1
H						1	2	

Table 6
Symmetrical form of matrix 1

	1				2	3			N_P	C_P
	B	C	E	F	D	A	G	H		
1										
B										
C										
E					1				1	1
F					1	1			2	2
2										
D			1	1		1			3	3
3										
A				1	1		1	1	4	4
G						1		3	2	4
H						1	3		2	4
SUM									14	18

Table 7
Matrix of N_{ij}

i/*j*	1	2	3	N_i	A_i	R_i
1	0	2	1	3	4	0.75
2	2	0	1	3	1	3
3	1	1	6	8	3	2.67
SUM				14	8	

The sum of the relationships through co-authorships for the author P = H is, thus, four ($C_H = 4$).

Two different matrices can be derived from the symmetrical matrix:

- Table 7 is the representation of the number of pairs N_{ij} with authors who have *i* publications per author, with authors who have *j* publications per author included in the bibliography.
  A_i is the number of authors with *i* publications per author.
  $N_i = \sum_j N_{ij}$ is the number of collaborators of all authors with *i* publications per author.
  $R_i = k = N_i/A_i$ is the average number of collaborators per author.
  A former investigation on the topic collaboration and Lotka proposed the average number of collaborators per author k to predict the productivity strata (Qin, 1995).
  An experiment was introduced in Lotka's Law with the new variable (*k*).
- Table 8 is the representation of the number of co-authorship relations C_{ij} between authors with *i* publications per author, and authors with *j* publications per author. The matrix C_{ij} was the pre-requisite for earlier studies (Kretschmer, 1999a, 2002 in more detail). Because of the possible fluctuation at that time, however, a classification of the data *i* and *j* was done corresponding to the logarithm resulting in a matrix C_{XY}. The structure of this matrix C_{XY}, as also of

Table 8
Matrix of C_{ij}

i/*j*	1	2	3	C_i
1	0	2	1	3
2	2	0	1	3
3	1	1	10	12
SUM				18

the corresponding relative values, has been described. The results of this study have been taken as a pre-condition for the present work.

Appendix B. Independence on the types of characteristics of persons and interaction

The well-ordered behavioural Gestalts emerge relatively independent of the type of personality characteristics and of the type of interactions. An example is shown in Fig. 10. The upper pattern is taken from Fig. 3. Age is used as personality characteristic and collaboration/communication as interaction. In the pattern below, education (X, Y) is used as personality characteristic and friendship (H_{XY}) as interaction. Source, from which the Gestalt in this study was developed: Table 1 (Marsden, 1981, p. 4). The values from the table were symmetrized (2450 data).

In the distribution of co-author pairs' frequencies N_{ij} (Figs. 2 and 8) co-authorships are the reflection of interactions and the characteristic of persons is the scientific productivity.

Appendix C. Independence on the used statistical methods of interaction measurement

In one of the former papers (Kretschmer, 2002) well-ordered mathematically described Gestalts of co-authorship networks could be shown relatively independent of the used statistical methods of the interaction measurement, cf. Fig. 11.

Methods of calculating observed frequencies C_{XY} (or C_{ij} respectively) can be found in Appendix A, of the homophylic index H_{XY} (or H_{ij} respectively) in Appendix D.

The methods of calculating relative frequencies (F_{XY}) can be found in Kretschmer (1999a).

For information: turning the Gestalt of the observed frequencies C_{XY} (cf. Fig. 11, first row, left) around 90° we receive rather the pattern of the distribution of number of co-authorship pairs N_{ij}, given on the left of the lower row in Fig. 1.

Appendix D. Homophylic index

To determine, whether the distribution of data within a matrix shows additional characteristic features, which have arisen independent of the distribution of the marginal sums N_i and N_j, the homophylic index H_{ij} can be used.

In some sociological studies of interpersonal relations in social networks of men (Wolf, 1996), this special homophylic index is used. That index provides information on the factor, by which the observed frequency in a cell of a matrix deviates from the occupancy of this cell that would otherwise be expected in case of statistical independence from characteristics. In order to calculate this index, we have to covert the matrix of observed frequencies N_{ij} into a new matrix using geometric mean. The special homophylic index H_{ij} is defined as:

$$H_{ij} = \frac{N_{ij}G}{G_i G_j} \tag{31}$$

where G is geometric mean of all matrix data, G_i is geometric mean of the data in row i, G_j is geometric mean of the data in column j, N_{ij} is the observed value and G_iG_j/G is the expected.

The homophylic index H_{ij} is the ratio of the observed and the expected values.

Appendix E. General characteristics of structures in interpersonal relations in social networks (partly presented in Kretschmer, 2002)

As for the structure of social groups, Metzger (1982, quoted by Metzger, 1986, p. 196) suggested that already in the prehistoric times of higher vertebrates – birds and mammals – principally two succinctly distinguishable conciseness forms of group structures had apparently existed that are also identifiable in man: step structure and ring structure. The step structure reveals individual members arranged in a hierarchical sequence (pecking order of the chicken run), whereas the "ring"-members, with their common concern in the center, are distributed "over equal heights".

In his deliberations about the formation of a group Metzger (1986, p. 222) also touched upon the proverb "Birds of a feather flock together" and gave it a grain of truth; but at the same time he suggested that similarity could only

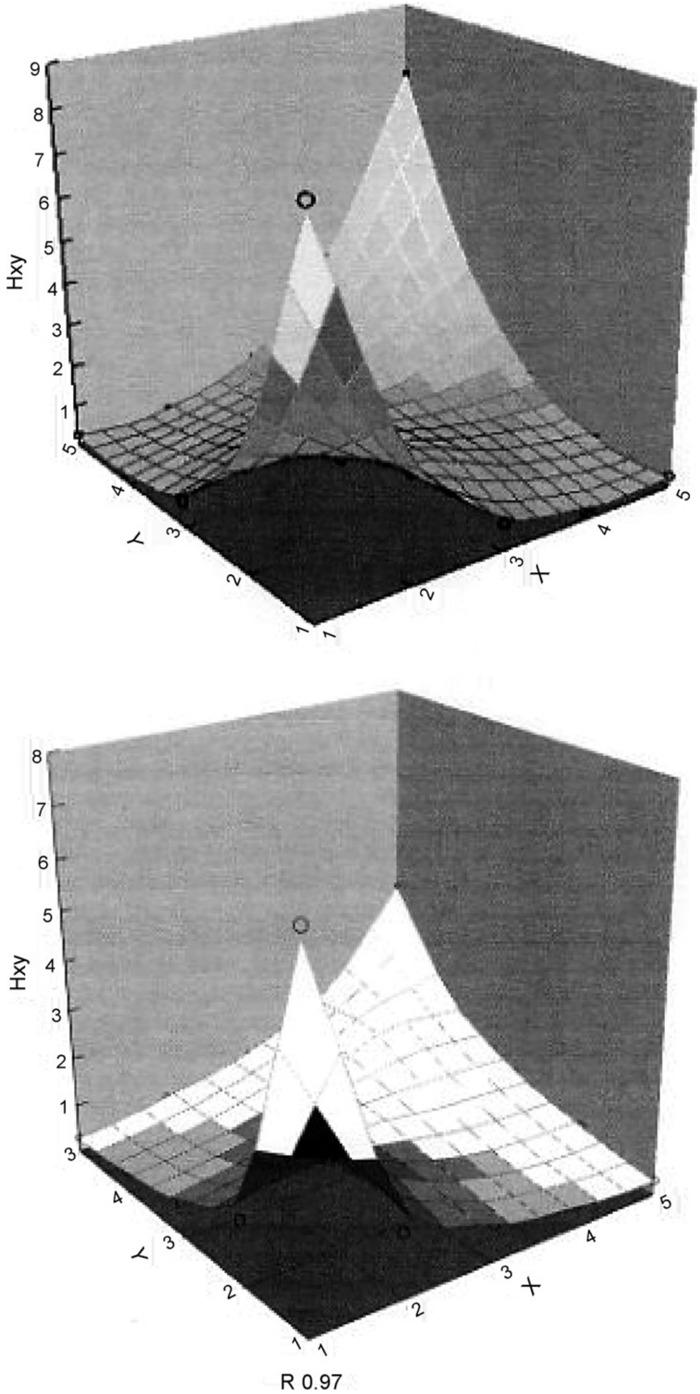

Fig. 10. Two Gestalts with both different types of personality characteristics and different types of interactions.

be viewed as one factor among many, irrespective of whether it may turn out to be an indispensable, or just sufficient requirement for group formation.

This point of view suggested by Metzger was adopted and, in this study, extended to additional knowledge from the literature on the characteristics of structures in social systems. The results of studies, as contained above, indicate that Metzger's definition of "Gestalt", which implies the balancing interaction of forces (tensions, field forces, etc.),

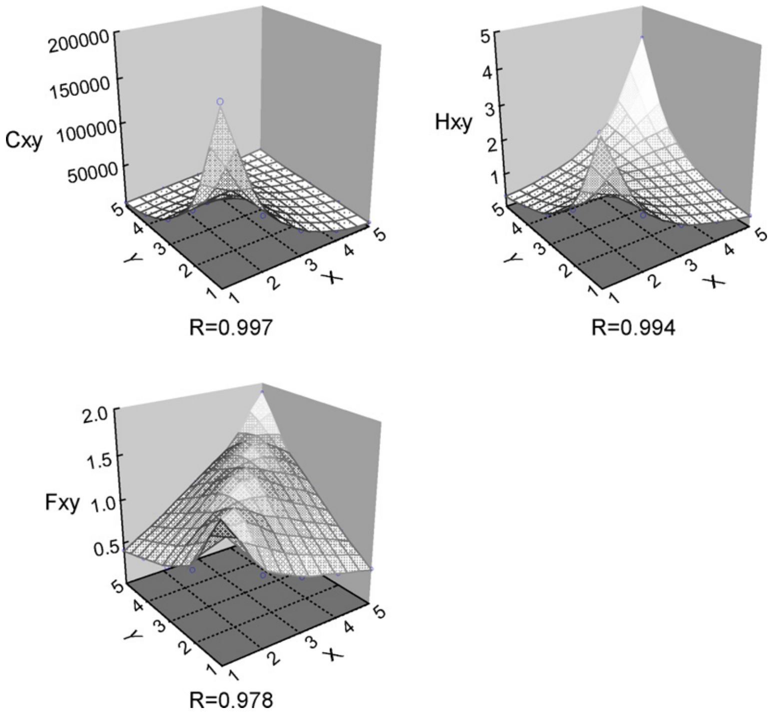

Fig. 11. Three Gestalts from international medicine and physics. Gestalts of observed frequencies (C_{XY}), Gestalts of the homophylic index (H_{XY}) and Gestalts of the relative frequencies (F_{XY}).

can be fully applied to social systems, even with retaining the validity of the conciseness (prägnanz) principle in a still more precise form than it would have been thought possible by Metzger himself: hence, there are structures existing in social systems that are strictly mathematically describable.

Without assuming the existence of a field-force equilibrium it would be difficult to explain how such mathematically precise gestalts could exist, which are thought to have been established by the free cooperation (self-organization) of scientists distributed over the entire world; cf. please, all three-dimensional figures of Gestalts in the co-authorship networks of this study.

When discussing the structural characteristics of interpersonal relations in social networks reference shall be made to one of Wolf's works (1996) rather than to the many studies conducted and contained in the literature. As a result, a definite structure can be identified that underlies to a great number of social processes of a distributive character, such as the spreading of diseases, the propagation of information, the change of views or the distribution of innovations. A generalization of this structure reveals three pivotal aspects:

- Over-coincidental similarity among persons in contact with each other ("Birds of a feather flock together").
- Decrease of interpersonal relations with declining similarity.
- Emergence of the "edge effect" (cf. below);

The author illustrates these three aspects on the basis of an empirical example (Wolf, 1996, p. 35). Independently of whether or not sociodemographic features, socio-structural characteristics or general approaches are taken into account, it has repeatedly been shown that persons with social contacts reveal greater characteristic similarities than it could have expected from persons with accidental associations. Relations may qualify as friendships, marriages, professional contacts or other types of relationship.

Wolf, in one of his empirical examples, studied similarity underlying relations of friendship due to common education. It is unequivocally obvious that those persons, preferably, became friends who had achieved the same level of education. These data of the same level of education can also be used to observe the edge effect. This term designates the more pronounced similarity of friendly couples that is observable at the edges of status features (referring also to persons at the lowest and also highest levels of education). Using the data file of Wolf it is possible to identify four-times-higher relations between high-school leavers and university graduates than it would be expected at a fortuitous choice of friends. The tendency to choose status-homogeneous friends is less clearly perceptible with persons having medium-level school degrees. Resultant at the same level of education a U-curve of data arised.

Two hypotheses are primarily suggested that should explain the edge effect. On the one hand it is maintained that the persons of the lowest and the highest group would be visibly exposed due to their social position and thus developed a stronger sense of affiliation than people having a medium-level social status. In addition, those people at a medium status display a stronger orientation towards career so that they are reluctant to have frequent contacts with people of the same level. On the other hand, it is suggested that the choices of people who are either at the very bottom or at the top are blocked in one direction.

Quite similar results were obtained in other studies, i.e. the distribution of persons within age groups. The persons belonging to the youngest and those to the oldest groups display a much stronger inclination to remain among their groups than this is the case for the medium-age groups.

The well-known proverb “Birds of a feather flock together” can be conveniently integrated into this theory, together with the empirical results published. Far less evidence is found, however, for the opposite saying “Opposites attract”, although several efforts have also been put into proving its correctness, just think of Winch, Ktsanes, and Ktsanes (1954), in which the complementarity of personality features was considered the decisive factor for partnership relations.

The descriptions available in literature on the crucial specifics of social structures refer to important and special aspects of individual phenomena. In Wolf’s empirical example and in those of many other authors it became obvious that only one of the two proverbs was used (Birds of a feather flock together), leaving out the other with its opposite meaning, also the U-curve in one of its positions (edge effect) and not vice versa. But apart from the U-curve, the assumptions are linear, for instance Wolf’s assumption (1996) on the “decrease of contacts with declining similarity” (It is an extension of the proverb “Birds of a feather ...”), or monotonously falling like the “Unidimensional Social Distance Model” of Marsden. Marsden operates on the premise (1981): “... that the likelihood of social intercourse between persons in groups is an inverse function of the distance between those groups along a single dimension” (p. 21). (Distance: distance in similarity.)

By contrast, this study will make an attempt to suggest that both opposing proverbs should only be perceived as the conspicuously visible state of a holistic process caused by conditions to which the system under study was subjected at the time of investigation. In addition, the same applies to both opposing views of U-curves, i.e. with edge effect on the one side, and the reverse case, on the other side.

Appendix F. Development of a mathematical function to describe gestalts in social networks (partly presented in Kretschmer, 2002)

F.1. Matrix of interpersonal relations

If one started from the assumption that all individual manifestations of social structure, as invariably mentioned in the literature, have come to interact within a system of the equilibrium of forces, a hypothesis might be established on the emerging forms of the adequate three-dimensional gestalts. These forms should be as simple, ordered, harmonic and uniform as possible according to the conciseness (prägnanz) tendency and should be structured in line with definite rules.

Their uniformity could be expressed by the visible retention of the balancing interaction of the different and also opposing individual phenomena in social structures, as known from literature, and could become visible in only one function. Thus, the diversity of patterns or Gestalts is then expressed by the variation of the parameters of this function, with the diversity being dependent upon the conditions causing these patterns (e.g. the environment). These many Gestalts can be classified into types in line with their similarity.

Both opposing proverbs and the U-curves in their contrasting situations give rise to reflect on the notion of complementarity. Capra (1996) wrote that the term complementarity (e.g. particle/wave) introduced by Niels Bohr has become a firm integral part of the conceptual framework within which physicists attentively weigh the problems of nature and that Bohr had repeatedly indicated that this idea could also be beneficial outside of physics. In conformity with above Capra also suggested that the modern notion of complementarity had existed already in a clear-cut manner in old Chinese thought, in the Yin/Yang teaching. Yin and Yang have to be seen as polar forces, as complementary tendencies interacting dynamically with each other, so that the entire system is kept flexible and open to change. Capra (1996) said: “It is important and difficult to understand for the people in the western world that these oppositions do not belong to different categories but are opposing poles of only one whole. There is no separate Yin and no separate Yang. All natural phenomena are manifestations of a continuous interplay between both poles, all transitions proceed in a direct and uninterrupted sequence. The natural order manifests itself in a dynamic equilibrium between Yin and Yang” (p. 32) (*translated from German to English by the author*).

It is conclusively consistent with all above considerations to seek a simple mathematical function (conciseness principle) for the description of “Gestalt” which can encompass the complementary tendencies (Yin and Yang) in their dynamic interplay and, accordingly, also the change of “Gestalt”.

The basic requirement for establishing this function is, however, the classification of persons according to a variable of personality characteristics, for example age or education, etc.

Following the interpersonal relations between these persons (variable Z), for example friendship or co-authorship, etc., will be recorded from the point of view of every individual person with value X of the variable of personality characteristics to all the other authors with value Y of this variable.

If the relations are recorded from the point of view of every individual person (with X) to all the other persons (with Y), then a symmetrical matrix of Z_{XY} is obtained.

For example there are three friends classified according to education (elementary school: $X, Y=1$; junior high school: $X, Y=2$; grammar school: $X, Y=3$; university: $X, Y=4$):

- person A with X (or Y respectively) = 1;
- person B with X (or Y respectively) = 4;
- person C with X (or Y respectively) = 3.

From the viewpoint of A with $X=1$ there is one relation recorded to B with $Y=4$, i.e. Z_{14} and one relation to C with $Y=3$, i.e. Z_{13}.

From the viewpoint of B with $X=4$ there is one relation recorded to A with $Y=1$, i.e. Z_{41} and one relation to C with $Y=3$, i.e. Z_{43}.

From the viewpoint of C with $X=3$ there is one relation recorded to A with $Y=1$, i.e. Z_{31} and one relation to B with $Y=4$, i.e. Z_{34}. (Symmetrical matrix of friendship relations Z_{XY}, see Table 9.)

In general according to this principle matrices of interpersonal relations between persons classified according to a variable of personality characteristics can be obtained.

The mathematical function $Z=f(X, Y)$ to describe three-dimensional Gestalts in such social networks should depend on the above named three pivotal aspects of the structure of social networks.

Three coordinated steps of approximation to the description of “Gestalt” will be discussed. Both the first and the second steps are only related to similarity or dissimilarity but the third one concerns the three aspects of structures in interpersonal relations in social networks in total.

Table 9
Symmetrical Matrix of Friendship Relations Z_{XY} between three friends classified according to education (X or Y respectively)

X/Y	1	2	3	4
1			1	1
2				
3	1			1
4	1		1	

F.2. Similarity and dissimilarity

Dissimilarity or contrary similarity between two groups of persons can be measured by the difference between X and Y.

The difference is chosen because of the above-mentioned symmetry in its absolute form:

$$|X - Y|$$

There is both a minimum of the difference:

$$|X-Y|_{\min}$$

and a maximum of the difference:

$$|X-Y|_{\max}$$

The similarity is highest at the minimum and lowest at the maximum and vice versa the dissimilarity is highest at the maximum and lowest at the minimum.

Moreover there is a complementary variation of similarity and dissimilarity. With increasing dissimilarity the similarity is decreasing and vice versa.

Under the condition dissimilarity A is defined as difference

$$\text{Dissimilarity}: \quad A=|X-Y| \tag{10}$$

similarity has to be defined as complement $A_{\text{COMPLEMENT}}$.

Therefore, with increasing distance D_A of the dissimilarity A from the minimum

$$D_A=A-|X-Y|_{\min}=|X-Y|-|X-Y|_{\min} \tag{32}$$

similarity has to decrease according to the same distance from the maximum:

$$A_{\text{COMPLEMENT}}=|X-Y|_{\max}-D_A \tag{33}$$

$$\text{Similarity}: \quad A_{\text{COMPLEMENT}}=|X-Y|_{\max}+|X-Y|_{\min}-|X-Y| \tag{11}$$

Resultant if the dissimilarity is moving to the maximum the similarity is moving to the minimum and vice versa.

Both the first and the second steps of approximation are two-dimensional representations of patterns only.

First step of approximation: The initial ideas on the mathematical function $Z=f(X, Y)$ were developed in pursuit of quantitative science research. It has for decades been shown here that the overwhelming majority of distributions of bibliometric data can be represented as power function, i.e. as a Zipf-distribution instead of a Gaussian distribution, as centrally used in psychology and in natural sciences.

For reasons of simplicity a power function was chosen as the starting point for considerations.

As a first step of approximation we can say the interpersonal relations are at least dependent on a power function of the dissimilarity between persons.

Since in case of "equals" the value 0 cannot be raised to a negative power, the term $|X-Y|$ is added by 1 resulting the power function:

$$Z'=\text{constant}\,(|X-Y|+1)^{\alpha} \tag{34}$$

$$Z'=\text{constant}\,(A+1)^{\alpha} \tag{35}$$

If the parameter α should be positive, then the idea of the proverb "Opposites attract" would be fulfilled in connection with the assumption of "Increase of interpersonal relations with increasing dissimilarity" (cf. example in Table 10 and Fig. 12, right).

Table 10
Example with $\alpha=+1$ and constant $=1$

$X-Y$	$\|X-Y\|$	$\|X-Y\|+1$	$(\|X-Y\|+1)^1$	$1(\|X-Y\|+1)^1$
−4	4	5	5	5
−3	3	4	4	4
−2	2	3	3	3
−1	1	2	2	2
0	0	1	1	1
1	1	2	2	2
2	2	3	3	3
3	3	4	4	4
4	4	5	5	5

Table 11
Example with $\alpha = -1$ and constant = 1

$X - Y$	$\lvert X - Y\rvert$	$\lvert X - Y\rvert + 1$	$(\lvert X - Y\rvert + 1)^{-1}$	$1(\lvert X - Y\rvert + 1)^{-1}$
−4	4	5	0.2	0.2
−3	3	4	0.25	0.25
−2	2	3	0.3	0.33
−1	1	2	0.5	0.5
0	0	1	1	1
1	1	2	0.5	0.5
2	2	3	0.3	0.33
3	3	4	0.25	0.25
4	4	5	0.2	0.2

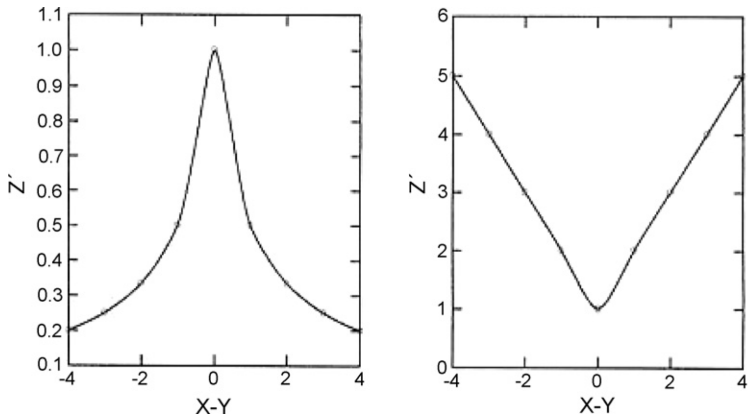

Fig. 12. Power function of similarity or dissimilarity (35); on the left, the parameter α is negative: "Birds of a feather flock together" and decrease of interpersonal relations with increasing dissimilarity. On the right, the parameter α is positive: "Opposite attract" and increase of interpersonal relations with increasing dissimilarity.

The proverb "Birds of a feather flock together" and extended by the assumption of Wolf's "Decrease of personal relations with declining similarity" or Marsden's "Unidimensional Social Distance Model" would all be complied with by the power function in which the parameter α is negative (cf. example in Table 11 and Fig. 12, left).

A power function with only one parameter (unequal to zero) is either only a monotonically declining or only a monotonically rising function, when referred to both proverbs: either "Yin" or "Yang". According to Chinese philosophy Yin and Yang are the opposite poles of a single whole. There is not an isolated exclusive Yin, or only a Yang. All transitions occur with a direct and uninterrupted sequence. The natural order is secured by the dynamic equilibrium between Yin and Yang.

In order to fulfil the inherent requirement that both proverbs with their extensions can be included in the representation, the second step of approximation will follow.

Second step of approximation: Like mentioned above with increasing dissimilarity similarity is decreasing and vice versa. Dissimilarity A and similarity $A_{\text{COMPLEMENT}}$ are two opposed varying factors and have to be inserted into the equation with one parameter each. It depends upon the parameters to what extent Yin has retracted itself in favour of Yang, or vice versa.

As a second step of approximation we can say the interpersonal relations are at least dependent on both a power function of the dissimilarity between persons and another power function of the complement:

$$Z^* = \text{constant}\,(A + 1)^{\alpha}(A_{\text{COMPLEMENT}} + 1)^{\beta} \tag{9}$$

It depends upon the two parameters to what extent Yin has retracted itself in favour of Yang, or vice versa.

In an attempt to convey, in theory, a graphic idea on this function a systematic parameter variation was made and the results are already shown in Fig. 7 above (explanation cf. Section 4.2).

As mentioned above the mathematical function $Z = f(X, Y)$ to describe Gestalts in social networks should depend on three pivotal aspects of the structure of social networks. Two of the three aspects are already included.

However, if you still want to incorporate the third pivotal aspect called "edge effect" both forms of the U-curve rather than only the two proverbs it is necessary to extend the formula according to the same principle (simplicity, conciseness, Yin/Yang) to the sum of X and Y, i.e. the formula that so far included only the difference between X and Y.

On the other hand, we can say we have extended our visualization up to two different Yin/Yang pairs. In the first pair, Yin was considered as dissimilarity (A) with $A = X - Y$ and Yang as similarity ($A_{\mathrm{COMPLEMENT}}$).

But in the second pair, Yin can be considered as low mixed value (B) with $B = X + Y$ and Yang as high mixed value ($B_{\mathrm{COMPLEMENT}}$) of a special personality characteristic.

The third step of approximation will follow.

F.3. Edge effect

Third step of approximation: Interpersonal relations Z at the main diagonal ($X = Y$) are more striking at the edges than in the middle although the differences between X and Y did not vary:

$$A = |X - Y| = 0 = \text{constant} \tag{36}$$

The values of Z_{XY}: Z_{11} or Z_{55} at the edges are higher than the values of Z_{22}, Z_{33} or Z_{44} in the middle. Whereas the differences between X and Y are constant the sums are varying.

In analogy, you find this phenomenon parallel to the main diagonal.

Therefore, when we put $A = |X - Y|$ and the opposite $B = X + Y$ the following formula is obtained under the condition that $B_{\mathrm{COMPLEMENT}}$ will be calculated according to the same principle as $A_{\mathrm{COMPLEMENT}}$:

$$Z = \text{constant}\,(A+1)^{\alpha}(A_{\mathrm{COMPLEMENT}}+1)^{\beta}(B+1)^{\gamma}(B_{\mathrm{COMPLEMENT}}+1)^{\delta} \tag{16}$$

As a third step of approximation we can say the Gestalt of interpersonal relations can be described by the product of the four power functions

- first of dissimilarity and second of its complement and
- third of the sum of the values of personality characteristics and fourth of its complement.

Accordingly, we have obtained a function with four parameters and one constant.

This function can encompass the complementary tendencies (Yin and Yang) in their dynamic interplay in two Yin/Yang pairs ($A/A_{\mathrm{COMPLEMENT}}$ and $B/B_{\mathrm{COMPLEMENT}}$).

How do the three-dimensional gestalts look like that are described in this form? In Fig. 5 above, five prototypes of Gestalts are shown. Proceeding in an example from $X_{\min} = 1$ and $X_{\max} = 5$, or from $Y_{\min} = 1$ and $Y_{\max} = 5$ respectively, you can obtain the patterns by way of variation of parameters, as shown in Fig. 5. Such Gestalts can also be generated with other values for minimum and maximum values of X and Y.

In the central Gestalt of Fig. 5 the proverb "Birds of a feather flock together" together with the extended version "Decrease of interpersonal relations with declining similarity" become conspicuously visible, but also the U-curve with the edge effect. However, in the lower Gestalt this tendency is less apparent, whereas "Opposites attract" with the extended version "Increase of interpersonal relations with declining similarity" have become more strongly perceptible.

The reversed U-curve is especially conspicuous in the upper Gestalt. In the left and the right ones the U-curve has converted into a one-sided tilt. A large number of many patterns could be drawn with the same simple function.

References

Bohm, D. (1980). *Wholeness and the implicate order*. London: Routledge and Kegan Paul.

Capra, F. (1996). Wendezeit. In *Bausteine für ein neues Weltbild*. München: Deutscher Taschenbuch Verlag GmbH & Co. KG.

de B. Beaver, D. (2001). Reflections on scientific collaborations (and its study): Past, present and prospective. *Scientometrics*, *52*, 365–377.

de Solla Price, D. (1963). *Little science, big science*. New York: Columbia Univ. Press.

Egghe, L., & Ravichandra Rao, I. K. (2002). Duality revisited: constructiion of fractional frequency distributions based on two dual Lotka laws. *Journal of the American Society of Information Science and Technology*, *53*(10), 789–801.

Fischer, E. P. (1997). Das Schöne und das Biest. In *Ästhetische Momente in der Wissenschaft*. München: Piper Verlag GmbH.

Glänzel, W. (2002). Coauthorship patterns and trends in the sciences (1980–1998): A bibliometric study with implications for database indexing and search strategies. *Library Trends*, *50*, 461–473.

Glänzel, W., & de Lange, C. (1997). Modeling and Measuring Multilateral Co-authorship in International Scientific Collaboration. Part II. A comparative study on the extent and change of international scientific collaboration links. *Scientometrics*, *40*, 605–626.

Glänzel, W., & Schubert, A. (2004). Analyzing scientific networks through co-authorship. In H. F. Moed, et al. (Eds.), *Handbook of Quantitative-Science and Technology Research* (pp. 257–276). The Netherlands: Kluwer Academic Publishers.

Grun, B. (1975). *Timetables of history*. New York: Simon & Schuster.

Hellemans, A., & Bunch, B. (1998). *Timetables of science*. New York: Simon & Schuster.

Kretschmer, H. (1999a). A new model of scientific collaboration. Part I: Types of two-dimensional and three-dimensional collaboration patterns. *Scientometrics*, *46*(3), 501–518.

Kretschmer, H. (1999b). Development of structures in coauthorship networks. In P. S. Nagpaul, K. C. Garg, B. M. Gupta, S. Bhattacharya, A. Basu, P. Sharma, & S. Kumar (Eds.), *Emerging trends in scientometrics* (pp. 157–198). New Delhi: Allied Publishers Ltd.

Kretschmer, H. (2001). Distribution of co-author couples in journals: "Continuation" of Lotka's Law on the 3rd dimension. In M. Davis & C. S. Wilson (Eds.), *Proceedings of the 8th international conference on scientometrics & informetrics* (pp. 317–326). UNSW, Sydney, Australia: Bibliometric & Informetirc Research Group (BIRG).

Kretschmer, H. (2002). Similarities and dissimilarities in co-authorship networks; Gestalt theory as explanation for well-ordered collaboration structures and production of scientific literature. *Library Trends*, *50*(3), 474–497.

Kretschmer, H., & Kretschmer, T. (2004). Comparison of rules in bibliographic and in web networks. In T. A. V. Murthy, S. M. Salgar, G. Makhdumi, P. Pichappan, Y. Patel, & J. K. Vijayakumar (Eds.), *Proceedings of the second international caliber 2004: Road map to new generation of libraries using emerging technologies* (pp. 470–486). Ahmedabad: INFLIBNET Centre.

Kretschmer, H., & Kretschmer T. (2006a). Well-ordered collaboration structures of co-author pairs in journals. In: P. Hauke, & K. Umlauf (Hrsg.), *Vom Wandel der Wissensorganisation im Informationszeitalter – Festschrift für Walther Umstätter zum 65* (pp. 107–129). Geburtstag. Bad Honnef: Verlag Bock + Herchen.-VI, 379 Seiten (Beiträge zur Bibliotheks- und Informationswissemschaft, 1).

Kretschmer, H., & Kretschmer, T. (2006b). Well-ordered collaboration structures of co-author pairs in journals. In *Proceedings of the 2nd national conference on S&T policy and management & international forum on science studies and scientometrics* (pp. 14–30).

Kretschmer, H., & Kretschmer, T. (2007a). Lotka's distribution and distribution of co-author pairs. In D. Srivastava, R. Kundra, & H. Kretschmer (Eds.), *Book of papers of third international conference on webometrics, informetrics, scientometrics and science and society & eighth COLLNET Meeting, COLLNET 2007* (pp. 164–176). New Delhi: Sonu Printing Press Pvt. Ltd.

Kretschmer, H., & Kretschmer, T. (2007b). Distribution of co-author pairs frequencies of the Journal of Biological Chemistry explained as social Gestalt. In D. Torres-Salinas & H. F. Moed (Eds.), *Proceedings of the 11th international conference of the society for scientometrics and informetrics* (pp. 870–871). Madrid: CINDOC, CSIC.

Kretschmer, H., Liang, L., & Kundra, R. (2001). Chinese–Indian–German collaboration results that provided the impetus for the foundation of COLLNET. *Scientometrics*, *52*(3), 445–456.

Laszlo, E. (1997). *Kosmische Kreativität*. Frankfurt am Main und Leipzig: Insel Verlag.

Lotka, A. J. (1926). The frequency distribution of scientific production. *Journal of the Washington Academy of Science*, *16*, 317–323.

Luukkonen, T., Persson, O., & Silvertse, G. (1992). Understanding patterns of international scientific collaboration. *Science, Technology Q Human Values*, *17*, 101–126.

Marsden, P. V. (1981). Models and methods for characterizing the structural parameters of groups. *Social Networks*, *3*, 1–27.

Metzger, W. (1986). Gestalt-Psychologie. In *Ausgewählte Werke aus den Jahren 1950 bis 1982 herausgegeben und eingeleitet von Michael Stadler und Heinrich Crabus*. Frankfurt am Main: Verlag Waldemar Kramer.

Miquel, J. F., & Okubo, Y. (1994). Structure of international collaboration in science—Part II: Comparisons of profiles in countries using a link indicator. *Scientometrics*, *29*(2), 271–297.

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *Proceedings of the National Academy of Sciences of the United States of America*, *98*, 404–409.

Okubo, Y., Miquel, J. F., Frigoletto, L., & Doré, J. C. (1992). Structure of international collaboration in science; typology of countries through multivariate techniques using a link indicator. *Scientometrics*, *25*, 321–351.

Pribram, K. (1997). Vorwort. In E. Lazslo (Ed.), *Kosmische Kreativität*. Frankfurt am Main und Leipzig: Insel Verlag.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos: Man's new dialogue with nature*. New York: Bantam Books.

Qin, J. (1995). Collaboration and publication productivity: An experiment with a new variable in Lotka's law. In M. E. D. Koenig & A. Bookstein (Eds.), *Proceedings of the 5th international conference on scientometrics and informetrics* (pp. 445–454). Medford: Learned Information.

Ravichandra Rao, I. K., Sahoo, B. B., & Egghe, L. (2003). A distribution of papers based on fractional counting: An empirical study. In J. Guohua, R. Rousseau, & W. Yishan (Eds.), *Proceedings of the 9th international conference on scientometrics and informetrics—ISSI 2003: An internationally peer reviewed conference* (pp. 241–250). Dalian: Dalian University of Technology Press.

Rousseau, R. (1992). Breakdown of the robustness property of Lotka's law: The case of adjusted counts for multi-authorship attribution. *Journal of the American Society for Information Science and Technology*, *43*, 645–647.

Sheldrake, R. A. (1988). *The presence of the past*. New York: Times Book.

Stapp, H. P. (1993). *Matter, mind, and quantum mechanics*. New York: Springer-Verlag.

Tijssen, R. J. W., & Moed, H. F. (1989). *Science and technology indicators*. Leiden: DSWO Press.

Winch, R. F., Ktsanes und, T., & Ktsanes, V. (1954). The theory of complementary needs in mate-selection: An analytical and descriptive study. *American Sociological Review*, *19*, 241–249.

Wolf, Ch. (1996). Gleich und gleich gesellt sich. In *Individuelle und strukturelle Einflüsse auf die Entstehung von Freundschaften*. Hamburg: Verlag Dr. Kovac.

Zitt, M., Bassecoulard, E., & Okubo, Y. (2000). Shadows of the past in international cooperation: Collaboration profiles of the top five producers of science. *Scientometrics*, *47*, 627–657.