• *ABSTRACT*

This paper reports on an attempt to create a new research tool, to follow the dynamics of science and technology. 'Socio-Technical Analysis' develops new quantitative indicators and graphic representations with which to map the development of a scientific controversy, or a technical innovation. The aim of the paper is to describe this approach, to stimulate reflexion and criticism, and to launch what can only be a collective project.

A Note on Socio-Technical Graphs

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We wish to report on an attempt to create a visual and conceptual space that might be of some use to scholars in the STS community, and to those of us engaged in teaching scientists and engineers. The aim of this Note is to stimulate reflection, to provoke criticism, and to exchange software and data in what can only be a collective project.[1]

In order to map the development of a scientific controversy or of a technical innovation, the STS field has learned to doubt the dichotomy between nature, on the one hand, and society, on the other.[2] It is not clear, however, what other narrative resources could replace the convenient alternation of 'not only . . . but also' ('not only social factors but also objective ones'; 'not only technical constraints but also political factors'). Alternative narratives have been developed under the heading 'actor–network theory' that stress the heterogeneity and variability of associations of human and non-humans.[3] Unfortunately, they are themselves made difficult to grasp because of the alternation between a social interpretation, that seems to reduce the content of science to a purely strategic show of force where might makes right, and a naturalistic interpretation that appears to grant back to non-humans the unproblematic presence of nature.[4] It appeared to us that it would be of some advantage to

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replace the distinction between nature and society by another set of distinctions that would cut across the first, and thus would render it difficult (or even impossible) to fall back on the previous debates. Hence the idea of socio-technical graphs (STG), that we are developing for pedagogical as well as for analytical purposes.

Mapping Scientific Controversies

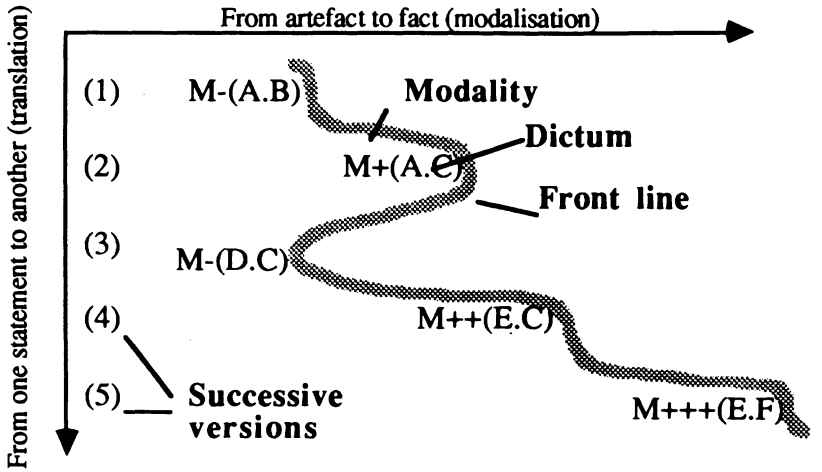
The principle of the STG is derived from earlier work by one of us on the mapping of scientific controversies. It has been shown that the trajectory of any statement may be mapped in two dimensions: the modalization made by others of the dictum, and the modification of this dictum.[5] The first dimension is an indication of the number of people convinced by a given statement — modalities going from extreme criticism to tacit acceptance — while the second dimension defines the amount of transformation that a statement undergoes, either by becoming a new statement, or by being associated with new elements. One of the results of studying controversies with those mappings is that it is impossible to move along the first dimension — modalization — without a deep transformation of the statement. This relative impossibility thus defines a front line — roughly equivalent to the frontier of science — that can be taken as the unique signature of a given controversy. It is this mapping that allowed us in the past to show the irrelevance of internalist explanations of science (where a statement is said to be accepted by its own internal virtue), and of externalist or consensual explanations (where a statement is said to be believed without the transformation of those who accept it, or of what is accepted). Instead, this mapping allowed us to define a statement as a series of transformations — or translations — undergone by a collective of people and things.[6] Any given statement thus becomes, not a point fixed in time and space, but a specific exploration of a socio-technical space: what is held together by whom, and who is held together by what?

Paradigms and Syntagms

The principle of the STG is a generalization and an operationalization of the study of scientific controversies.

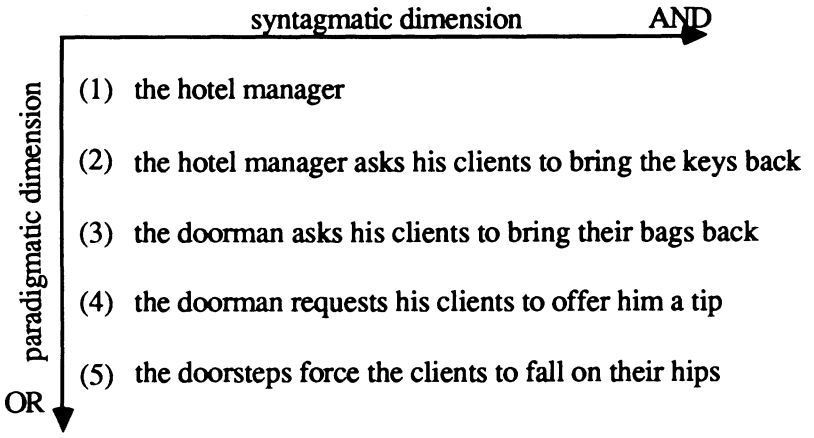
The first task is to make more precise the definition of the two

FIGURE 1



Successive versions of the transformation of a dictum and of its modalities (the signs − and + as well as the position indicating the degree of rejection or acceptance). The point of this diagram is to show that the dictum accepted at version (5) is deeply different from the initial statement (1).

FIGURE 2



A succession of sentences may be defined either because they add new meaningful units to a sentence (AND) or because they substitute new alternative words (OR) to one or several units inside a sentence.

dimensions which will be used as the 'latitude' and 'longitude' for the mapping process. Linguistics offers two useful definitions. It is traditional in the exploration of a linguistic structure to distinguish the 'syntagmatic' dimension from the 'paradigmatic' one.[7] A 'syntagm' is a set of different units that may be added in a sentence while still being meaningful. A 'paradigm' (no relation to Kuhn's meaning) is the set of different units that may replace a unit in a syntagm without rendering the sentence meaningless. For instance the following set of sentences explores the syntagmatic dimension:

the hotel manager
the hotel manager asks his clients
the hotel manager asks his clients to bring their keys back
the hotel manager asks his clients to bring their keys back to the front desk

while this set explores the paradigmatic dimension:

the hotel manager ask his clients to bring their keys back
their bags
their towels
their maps

The first (syntagmatic) dimension defines how many different elements may be held together in a meaningful assemblage, while the second (paradigmatic) dimension defines the meaningful substitutions that may be done at each point along the syntagm. The first dimension defines *association*, and the second *substitution* — or, still more synthetically, AND and OR.

An exploration of a locutor struggling for a sentence through the syntagmatic and the paradigmatic dimensions of language may be mapped on to a diagram (Figure 2) that resembles that of Figure 1.

Unfortunately, the narrative of a scientific controversy or of a technical innovation is different from the exploration of a linguistic structure in one crucial aspect. For each language, there exists a more or less fixed structure that endows each locutor with the basic competence to judge what is a meaningless association or substitution. The sentence 'the hotel manager beats his clients to bring their keys back' would be considered pragmatically meaningless, while the sentence 'the hotel manager eats its clients to bring us key back' would be deemed grammatically incorrect. No such grammar is available to decide whether a transformation of a scientific statement is possible

or impossible, since research and innovation aims at circumventing the pre-existing limits of any given pragmatics.

Not only is there no deep, stable, *a priori* structure to evaluate the meaningfulness of a given association or substitution in the narratives of an innovation,[8] but the very definition of units is in debate, and so are the various points of view of the many locutors. This is precisely the reason why we all study controversies and innovation — that is, science in action. While we may retain the two dimensions AND and OR that extend earlier work on controversies, we have to devise an additional set of specific mapping principles in order to cope with the peculiar difficulties of our field.

Specifications of the Socio-Technical Graphs

As usual, it is easier to define the minimal constraints of the STG than to devise the specific visualizations and software that will implement them.

A good mapping of the trajectory of a statement should respect the following specifications.

— The mapping will always start from a narrative that will be appropriated from other sources (historians' accounts, interviews, printed documents, databanks); it will never be more than a re-representation in graphic form of an already existing text,[9] and so will never be more concrete, more accurate, more complete than the narrative it sums up.

— The aim of this mapping, like that of any other instrument, is to get rid of most of the initial information, while outlining the features that are deemed relevant to our enquiry.[10]

— The aim is not to compete with what the 'thick narrative' of an historian or of an ethnographer of technology could provide, but to offer a quick and easy comparative basis for many narratives coming from many sources.

— The mapping will not re-employ any element coming from the society/nature dichotomy (for instance the human/nonhuman divide). We should never have to presume the stability of either the objects (internalism) or the subjects (externalism); a trajectory is to be defined only by association and substitution of a set of units.

— The mapping will be focused on outlining the specific phenomena of our field: heterogeneity of the alliances, local character,

variations of scale, continuous drifts of the projects and statements, black-boxing and stabilization, sudden reversals of forces.

— The units should not be defined by their essence, but only by their action; they have to be variable, and they should be defined only by the trajectories in which they are engaged. In other words, trajectories and units should be cross-defined.

— The mapping should be observer-dependent, allowing a quick and easy comparison of diverse and sometimes contradictory accounts of the trajectories and of the units.

— The shift between accounts should remain possible by comparing their degree of dispersion or alignment, and not by having to choose one over another.

— The visual displays should be optically coherent, so that the representation is readable in a space where all or most of the geometrical features are rendered meaningful. Once the minimum training to read the map and the conventions is obtained, there should be no added idiosyncratic features that could limit the inspection and the comparison between researchers, or between case studies.

— Finally, the whole procedure should be capable of implementation on one of the existing software programs, and be usable for research as well as for teaching purposes.[11]

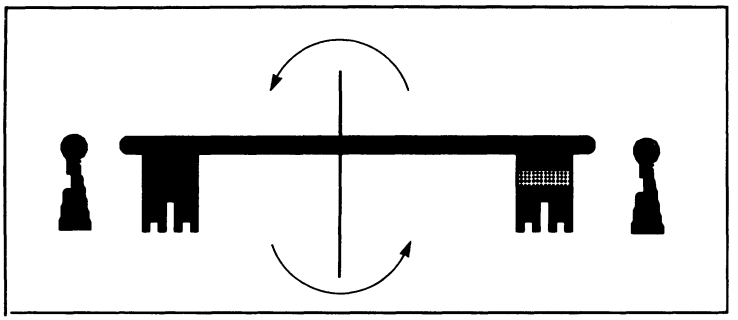
There are no doubt many different ways to fulfil these specifications for STG. We want to describe one family of such graphs that will certainly be replaced by many more sophisticated tools in the near future.

Recoding a Simple Narrative

Let us choose a very simple example of a narrative to show how it could work.

Name of the project: Berliner Key[12]
Name of the locutor: Bernhard
Text to be encoded: 'Since asking tenants of a cooperative building to relock front doors behind them at night did not seem sufficient to be obeyed, the Berliner Homeowner Association printed signs 'Please relock the doors behind you at night' to be put out by the janitors; when that failed as well, they then decided to install a new lock with such a strange mechanism that the tenants could not get their key back without relocking the door behind them. When that was done they extracted

FIGURE 3
The Berliner Key



compliance from most tenants who now dutifully relock the doors in order to get their key back.'

This narrative, told from one point of view — Bernhard's — outlines a (micro)controversy between two groups (the Berliner Homeowner Association and the Tenants) that goes through a series of successive transformations (verbal injunctions, printed signs, new mechanism) to a point where the association's initial goal appears to be reached by enrolling the undisciplined tenants.

The question for STG is not to evaluate the credibility or realism of such a story, but only to see how it could be coded into a graph that would retain some of its relevant features for following an innovation.[13]

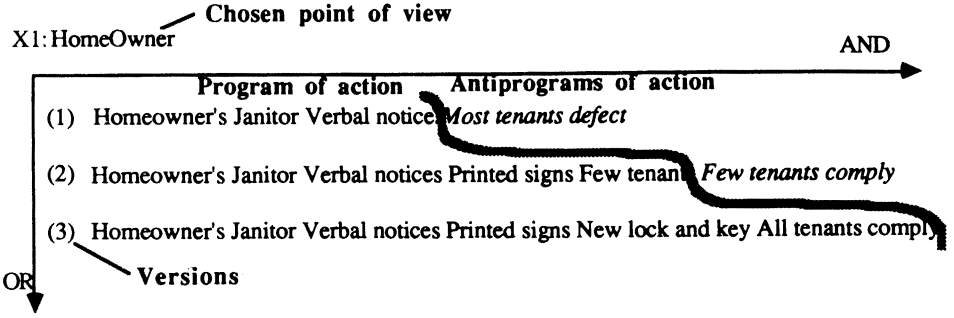
The chosen point of view — not necessarily the same as that of the narrator — is denoted X1, X2, and so on.

A first syntagm is defined by an association of units. Each of those units is considered as an actant, and a specific file is opened for each of those actants when they enter a syntagm (see below).[14]

A syntagm is defined only by associations of actants, with no attempt at qualifying the relations between units. That they are associated together or not is the only piece of information retained.[15]

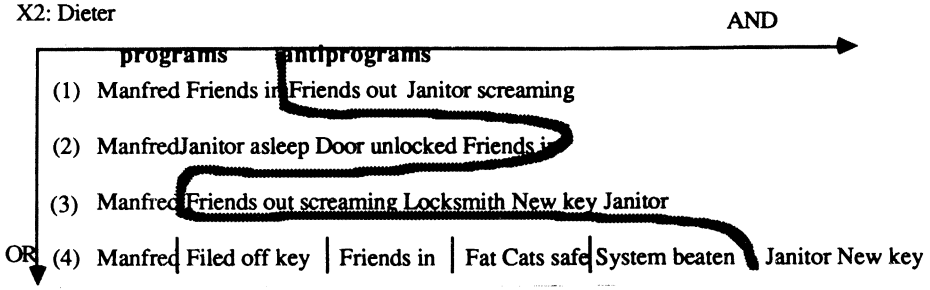
Each syntagm is reconstructed into two branches: the programme of actions that associate the allies; and the antiprogrammes that gather the opponents.[16] The definition of what counts as an anti-

FIGURE 4



The diagram extracts a set of words, divides them into programme and antiprogrammes, and lists from one version to the next those who appear, who disappear and who shift from one side of the front line to the other.

FIGURE 5



Same diagram as in Figure 4, but with a narrative that modifies the point of view, the actants and the shifting frontier of allies and enemies.

programme depends on the choice of a point of view. If the story above is told from the tenants' side, the programme of action will be 'to remain free to let friends go in and out at night without bothering to relock the front door'. The boundary line between programmes and antiprogrammes defines the front line the evolution of which we want to be able to trace.

The first syntagm is then modified in only two ways so as to obtain the next version — coded (2), (3), and so on: either a new element is added to the syntagm, or one of the old elements is replaced by another one. As long as there is no information to tell us that an actant has left a syntagm, it is repeated from one version to the next.

When a series of actants stay together through successive versions without defecting, they may be aggregated in a black-box and given either a new name or the name of one of the actants.[17] It is important, however, to be able to reopen the black-box and to redistribute its components if necessary. At the beginning of a narrative, each actant is a black-box that we will learn to reopen (or not) only later, when comparing accounts.

Once this recoding is done, the story is limited to its bare outline and encapsulated in one diagram. The evolving drama of the story is, however, retained: every time the Homeowner Association adds a new element, they extract more compliance from the Tenants. With the invention of the new Berliner key they make the Tenants shift from the antiprogrammes to their programmes (see Figure 4).

Simple tests may be done visually to see which actant is stable, which one is reliable, which one induces deep modifications when added, and which one is insignificant (see below). Although relations can no longer be qualified — since grammar is reduced to semantics — it is still possible to obtain very primitive association rules such as: for observer X1, at version (3), when the actant 'New lock and key' is introduced, then 'Tenants' go from programme to antiprogramme, provided the other actants of version (2) remain present. This tells us something about the compatibility and incompatibility of tenants, keys, homeowners, janitors and printed warning. We lose most of the information given in the narrative, but we preserve the feature that interests us most: when an ally defects or is made reliable.

Circulating through Contradictory Accounts

However, since there exists no structure of science and technology

that could tell us *a priori* which are the accounts that are meaningful and which ones meaningless, it is essential for us to be able to compare contradictory accounts. It is also the only way to repair the danger of giving a functionalist account of programmes and antiprogrammes. What is dangerous in a functionalist argument is not the function *per se*, but the essentialism that goes with it, and the avoidance of controversies about what counts as a function. In other words, relativism should redeem the sins of functionalism. This is why it is so essential to be able easily to shift points of view.

Name of the project: Berliner Key
Name of the locutor: Manfred
Text to be encoded: 'It is a pain in the neck not to be able to let friends in and out of our rooms at night. The janitor is always there to relock the door and our friends have to scream to be heard from the street. Before, we could go down and leave the door unlocked when the janitor was asleep. But the bloody locksmith invented his new key and we were forced to relock it. No problem for me. I filed off my key and I do not have to relock it! And the Fat Cats believe they are safe . . . In alternative Berlin we know how to beat the System.'

For this new account, it is possible to draw another diagram of the same type as the former one (see Figure 5).

This is a rather different story. Only the Locksmith and the New key are the same as in the former one, but, since they are not associated within the same syntagm by the two observers X1 and X2, they are not exactly the same.[18] The Janitor appears in the two stories, but is modified in the second since *it* now has the additional property of being asleep! To the New key is added a crucial ingredient that reverses the previous state of associations: the File. As for the disciplined tenants of the first story, they have become one clever tenant, Manfred, who beats the System. The Homeowner Association is not mentioned in the second story, but another actant appears that might be a synonym: the Fat Cats.[19]

Tests may now be made in order to decide the degree of dispersion of the two accounts. If we superimpose version (3) of account X1 and version (4) of version X2 (the sign '//' designating the front line between allies and opponents), we may obtain results such as this:

X1 (3) Homeowner's *Janitor* Verbal notices Printed signs *New lock & key* All tenants comply//

X2 (4) Manfred Filed off key Friends in Fat Cats safe System beaten//*Janitor New lock & key*

FIGURE 6

Card number : 1
Name of actant Janitor

Observer	N°	Version
X1	(1)	Janitor Homeowners Verbal notices//Most tenants defects
...	...	...
X2	(2)	Janitor asleep Dieter Door unlocked Friends in
...	...	...

An actant is equivalent to the list of the actions in which it is engaged in the various accounts. If the actant gains coherence and solidity it may be granted an essence in addition to its existence. A substance is thus added to its qualities. Then, it is endowed with humanity or non-humanity. But each of these operations is reversible and should be documented.

If the two accounts were aligned, it would mean that whenever an actant is cited in one narrative it is inserted in the same syntagm in the other. If two accounts were totally divergent, it would mean that no two actants are the same, or that they are engaged in completely different syntagms. Because of the principle of symmetry, it is crucial for our goal to have the same visualizing devices for convergent and divergent accounts.[20] The analyst should never have to decide *a priori* if there is a unity in the story he or she is telling (apart from being studied by the same analyst, and to have the same code name — for instance, here to be part of the 'Berliner Key' project).[21]

Going from Trajectories to Actants and Back

The same relativism should be maintained for the very definition of the actants. According to the specification above, we do not know what an actant is, apart from the fact that it is mobilized in one version of one narrative viewed from the point of view of one observer. At the beginning an actant is nothing but a word in a text, a label. If for each actant named in a story we open a card, this card will then be incremented by the various entries alluding to this actant in all the various accounts. Who for instance is the 'Janitor'? We know strictly nothing about this actant, except that the card that bears its name will read like Figure 6.

An actant is defined by all the syntagms in which it is successively engaged, exactly as a syntagm is defined by all the actants it associates. But, in the same way that it is possible to compare the degree of convergence or dispersion of two accounts, it is possible to compare the relative coherence or incoherence of an actant. If, in all the successive versions, or in all the accounts, the same actant's name is associated with the same syntagm, then we can consider it as a predictable entity, or as a black-box. If, on the contrary, no two accounts offer the same syntagm for the same name, then we will have to consider it as an unreliable actor. Between those two extremes, variations are more interesting. An actant may gain predictability from one version to the next, or from one account to the next, or it can lose predictability. It is essential to record this variable geometry of the actant, since it is one of the main discoveries of science studies.[22] The Tenants, for instance, vary from one version to the next in the first account, and vary again when we go from 'All the tenants comply according to X1' to 'Manfred defects and beats the System according to X2'. If our visualization does not allow us to follow the moving shape of actants which are endowed with variable scale, motives, interests and definitions, and which can become stable or unstable, it will not be usable for tracing the trajectories of innovations or of controversies.

One point deserves to be underlined again: it should be clear from the definition of an actant that exactly the same principles apply for the word 'file' in the second story, although a file is considered a thing. We learn something on *what is* a file when we see that its association in version (4) completely transforms the situation — according to Manfred:

> X2 (3) Manfred//Friends out screaming Locksmith New key
> X2 (4) Manfred *Filed off key* Friends in Fat Cats safe System beaten//*Janitor New lock & key*

The essence of a file is modified by this narrative; that is, the card 'File' is implemented with a new syntagm that makes it able to modify the state of the relations between Fat Cats and Tenants in Berlin. Since an actant is only what it does, there is no other way to modify the essence than by modifying the action inside the card. This modification introduced by X2 may be small compared to all the other accounts in which 'a file' is used unproblematically. But we know from our work in science studies that such is not always the case. The interpretative

flexibility of a thing may be as great as that of an individual or of a social group like that of the Tenants above.[23] It is essential to apply the same test of coherence or incoherence to the cards that designate non-humans, as to those which designate collective beings or individual humans. The *isotopy*, as semioticians say[24] — the stability in space and time of an actant in a narrative — should not be taken for granted, but obtained by what the various stories make of it. In principle, a non-human like a 'file' is no more and no less flexible than a collective person like 'Homeowner Association', or an individual like 'Manfred'. More exactly, the many differences between them should not be defined *a priori*, but should emerge from the chains of associations making up their definition.[25]

Does this mean that might makes right? An anonymous referee made what appears to be a cogent criticism of the 'simple-minded counting of actants', by citing the following example:

> In developing his telephone for Western Union in 1877, Thomas Edison incorporated far *more* technical elements in his design than Alexander Graham Bell, and Western Union was able to utilize its *larger* existing network to introduce *more* of Edison's telephones faster than its *tiny* rival American Bell. Yet American Bell *prevailed* and *forced* Western Union and Edison to cede the US telephone to them. Why? Not because American Bell had *more* telephones, capital, or enrolled actors but because Bell and his backers were able to assemble a *small* but *unassailable* set of patents covering the telephone. In network terms, American Bell prevailed over the powerful Western Union not through the *number of actors* but by bonding *several key* non-human actors together.[26] (our emphasis)

It is precisely because we do not know the force of any given actor that we have to be completely agnostic in allocating their definition. In this story, a well defined patent is stronger than capital and techniques, because it allows the weak Bell to tie himself to the whole legal system of the United States. As the words we have emphasized indicate well enough, there is always a metrology at work in the accounts of those who critique the slogan 'might makes right' — a metrology which is always, in the last instance, some sort of 'simple-minded counting of actants' ('prevailed', 'forced', 'unassailable', 'key non-humans'). The goal of STG is to push the analysts to be explicit about this metrology that allows them to say, as in the case of Bell's patents, that right makes might, that right is thus *stronger* than might. It is this very variation of scale that we want to be able to document, whereby a tiny actor becomes stronger than the strong, but without believing in some *a priori* definition of who or what is strong and who or what is weak.

Implementing the STG on Hypercard

In this presentation of STG, we have defined two forms of *cards* and three types of indicators or tests.[27]

There are two types of cards:

— One that summarizes the shifting trajectories of associations and substitutions considered by various observers (the Project card according to X).
— Another that recapitulates the actants' varying definitions (the Actant card).

There is no essential difference between them except that, in the first case, we follow the transformations of a syntagm through the substitutions of each of its components, while in the second we follow one component through all the syntagms in which it is engaged. It is like shifting from the study of sentences to that of words.

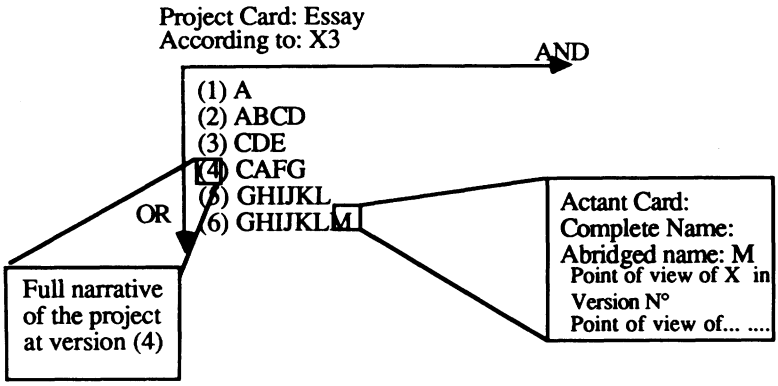
In addition, we have indicated the necessity of having three types of *indicators*:

— A first group of tests should analyze the path of one trajectory (Evolution Indicators).
— A second group should analyze the dispersion or alignment of various accounts of the same trajectory and thus decide, among other things, how much it is 'the same' (Observer Indicators).
— The third group will provide us with the degree of coherence or incoherence of a given actant, and thus determine its relative stability (Isotopy Indicators).

Although the name and application of these tests are different, they are all similar in their principles, since they compare chains of associations and substitutions. We have implemented these two cards, and are implementing these three types of tests, on Hypercard in order to check the feasibility of the specifications above. To keep this Note short, we will limit the presentation to a few of those indicators.

In trying to present the outline of our mapping, we run into a difficulty due to the difference between a Hypercard medium and a text. Texts oblige one to choose between the detailed narrative and its simplified and abstracted version, whereas hypertexts allow one to circulate very fast between an abstracted version and the detailed narrative from which it originates. Thus the bare outline that follows

FIGURE 7



Each actant is both a letter of the alphabet chosen according to its ranks of entry into the story (told by observer X3) and a Hypercard 'button' that allows one to go back to the Actant card that lists all its 'actions'. It is possible by clicking on the 'button' version to go back to the initial narrative. (Cards may also include texts, pictures, films.)

will appear abstract, since the actants will be reduced to numbers, but if the readers can 'click' on each of those numbers transformed into 'buttons', they will get back to the narrative, and will get a more concrete feeling for what we are after.

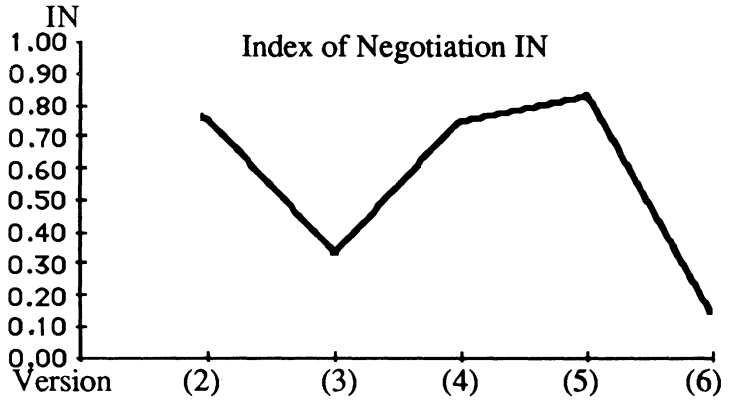
Let us replace actors' names by letters of the alphabet, and let us eliminate, for the sake of simplicity, the actors who make up the anti-programmes.[28] Then the narrative takes the following shape. We choose here an imaginary example that includes one exemplary moment of renegotiation — version (3) — in between two moments of persuasion — (1) to (2) and (4) to (6) — and arrive at Figure 7.

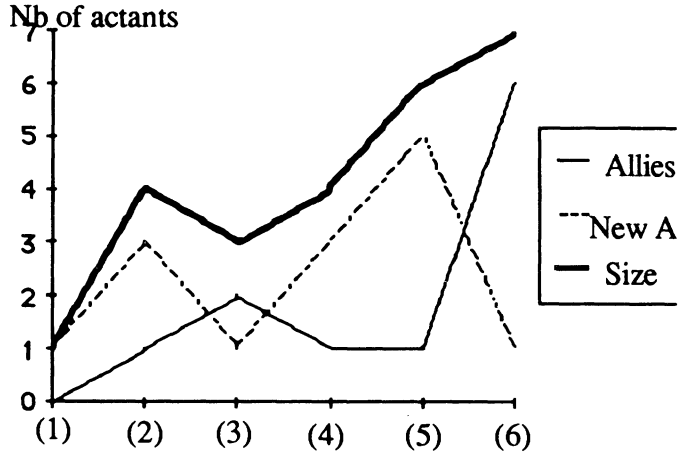
Calculating the Indicators

Such a diagram makes it possible to calculate a number of indicators, which should help in evaluating the unique signatures of a trajectory and in comparing projects and accounts.

Which are the most interesting Evolution Indicators for following one given innovation? The first one is obviously the indicator S for

FIGURE 8





Signatures of a trajectory of associations and substitutions on the same case. Those indicators simply aim at directing attention to the versions where interesting renegotiation seems to happen.

Size, which gives the number of associated elements in each successive version. The second indicator of interest to us is the one that compares the number of elements maintained from one version to the next: we will call it A for Allies. We shall call the new actors recruited in moving from one version to another N for New actors. For each version, identified by a subscript n, we thus obtain:

$$S_{(n)} = A_{(n)} + N_{(n)}$$

(Note that, for the moment, the 'seniority' of an actor is relative only to the transformations that occur from one version to the next. Thus a 'lost' actor that gets recruited a second time counts as a new actor — see Appendix.)

Thanks to these first few indicators we can define an Index of Negotiation, IN:

$$IN_{(n)} = N_{(n)} / S_{(n)}$$

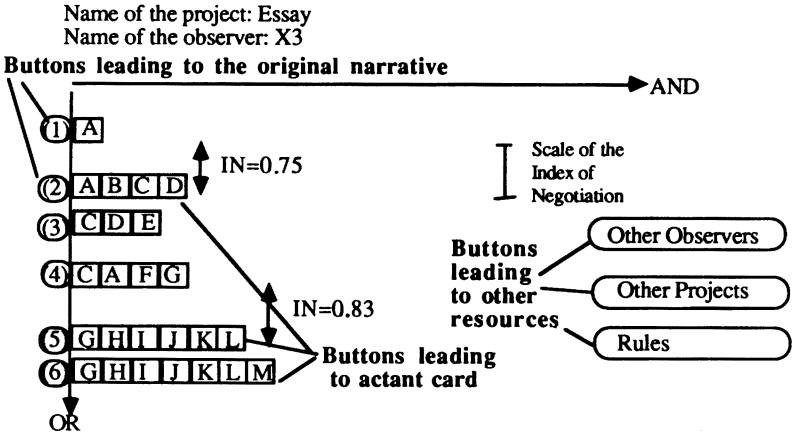
The smaller the value of this index, the less the innovator has to negotiate to maintain his or her project in existence. Conversely, a high value of this index means that the project has to be extensively renegotiated. For our imaginary example, we obtain the following numbers:

	S (Size)	A (Allies)	N (New actors)	IN (Negotiation)
(1)	1	–	–	–
(2)	4	1	3	0.75
(3)	3	2	1	0.33
(4)	4	1	3	0.75
(5)	6	1	5	0.83
(6)	7	6	1	0.14

If we now draw the graph of our first three indicators, we obtain a series of curves (Figure 8) which are specific for the innovation under examination, and which should help in determining what part of the narrative one may wish to examine in more detail.

By using IN, the index of negotiation, and S, the index of size or of association, we can now recapitulate the path of an innovation and build, with the same 'buttons' as above, the 'Home card' of a project.

FIGURE 9



This is the Socio-Technical Graph properly speaking. It is designed as the Home card of a Hypercard stack. Each button leads to the actant card. Each version button leads to the original narrative (which could be made of graphic or video documents in a pedagogical interface). Each version is spaced from the former one by a distance that reflects the index of negotiation IN.

We will call this map the Socio-Technical Graph of a project: see Figure 9.

Conclusion

Similar indicators may be devised to evaluate the dispersion of accounts and the coherence of actants. If several accounts converge, and if the actants they mobilize have a high degree of coherence, then the degree of predictability of the project increases. At the limit it might even be possible to predict the next move. If, on the contrary, there is a high degree of dispersion among accounts, and if the actants they enrol have no stable definition, the interpretative flexibility will

be so great that no prediction will be possible.[29] In either case, the STG is built along the same principles and simply records the shifting shapes of the alliances. Indicators of Evolution, Observer and Isotopy simply help in guiding the reader through the databank, and in highlighting important phases.

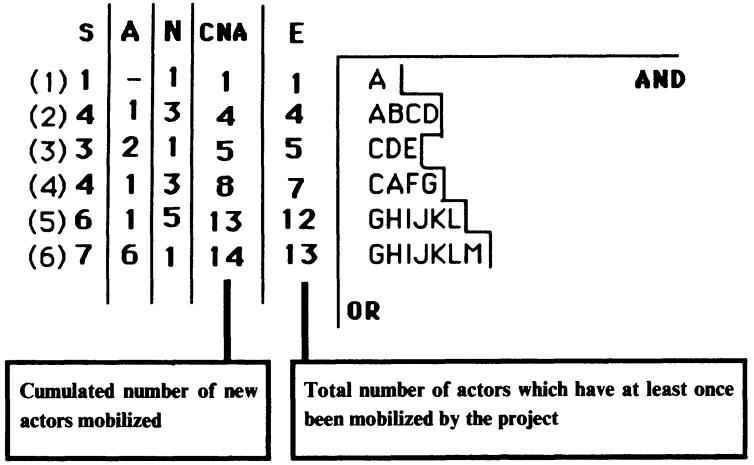
More work is obviously needed to implement the specifications above, to be able to treat, for analytical purposes, large and complex case-studies. Still more work is needed to turn the shell of the STG into an interactive simulator adjusted to the teaching of science students. We welcome discussion of this Note, and collaboration on finding other ways to set up socio-technical graphs.[30]

• APPENDIX

It is possible to produce a synthetic characterization of the paths of innovations by defining a few more Evolution Indicators.[31] Until now, we have only compared different versions one by one. It is clear, however, that new actors can be remobilized by a version (n) which had already been mobilized by previous versions. Thus the cumulation of new actors from version to version over a given period can be different from the total number of actors associated with the project during this same period. We will therefore distinguish between Cumulated New Actors, CNA, and the exploration, E, of the project. CNA indicates the variation of the degree of attachment of the actors, while E represents the size of the population of actors mobilized by the project. In the examples above, we obtain E by considering the rank of letters in alphabetical order. E is a synthetic indicator which allows us to distinguish innovations that explore a large number of new actors from those that recombine a small number of potential allies in different configurations. So, for the example above, we obtain Figure A1.

Some projects are strongly attractive. This means that all the new actors which one day participated in the project in a version (n), find themselves associated again in the next version (n + 1). These actors constitute the aggregate of new actors: they are those who move from the index N(n) to the index A(n + 1). Conversely, some of these new actors have disappeared in the (n − 1) version; these are the lost new actors. In order to measure our innovation, we calculate its Yield

FIGURE A1



Index, Y. This index is calculated by dividing [(the cumulative number of the aggregate of new actors) − (the cumulated number of lost new actors)] by the exploration E. The indicator thus obtained measures either the capacity of a project to attach itself to the majority of the actors it mobilizes or, on the contrary, its tendency to visit a large number of new actors without fixing itself anywhere.

$$Y_{(n)} = [(\Sigma \text{ ANA}) - (\Sigma \text{ LNA})]/E_{(n)}$$

where ANA = aggregate of new actors

and LNA = lost new actors

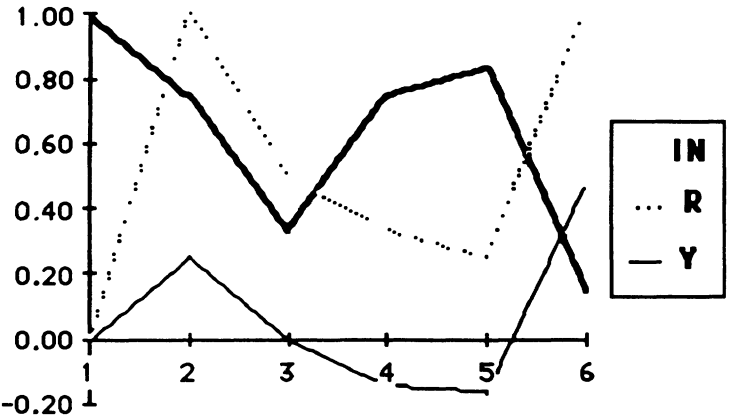
This index takes values between '1' and '− 1'.

A final synthetic index can be obtained by dividing the number of associated elements A which remain stable in a version (n) by the size S of the previous version (n − 1). This index defines the 'reality', R of the project — that is, the 'resistance' it needs to be able to move from one version to the next without putting what it already acquired into question:

$$R(n) = A(n)/S(n - 1)$$

All these indicators allow us to compare trajectories whose size and content are completely dissimilar, and which come from vastly distant empirical sources. For the three indicators of negotiation (IN), reality (R), and yield (Y), we obtain profiles for the above example as presented in Figure A2.

FIGURE A2



Indices of Negotiation (IN), Reality (S), and Yield (Y) for the same example.

• *NOTES*

An earlier draft of this paper has been entirely rewritten to take into account four anonymous referee reports and extended criticisms by Mike Lynch. It has also benefited from an earlier version of Jim Scott's paper (see note 1, below). The Hypercard stack of our preliminary implementation is running on a Macintosh II. Another presentation of those arguments with an extensive historical example may be found in B. Latour, P. Mauguin and G. Teil, 'Une méthode nouvelle de suivi des innovations. Le chromatographe', in D. Vinck (ed.), *La Gestion de la recherche: Nouveaux problèmes, nouveaux outils* (Bruxelles: De Boeck, 1991), 419–80, and B.

Latour, 'Technology is Society Made Durable', in J. Law (ed.), *Technology, Power and the Modern World* (Keele, Staffs.: Sociological Review Monograph, in press). This work has been supported by a grant from the Ministère de la Recherche et de la Technologie and from the Innovation Department of Rhône Poulenc.

1. J.K. Scott, 'Exploring Socio-Technical Analysis: Monsieur Latour is not Joking!', *Social Studies of Science*, Vol. 22, No. 1 (February 1992), 59–80.

2. B. Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press, 1987).

3. M. Callon, J. Law and A. Rip (eds), *Mapping the Dynamics of Science and Technology* (London: Macmillan, 1986).

4. See O. Amsterdamska, 'Surely, You Must be Joking, Monsieur Latour! Review of *Science in Action*', *Science, Technology and Human Values*, Vol. 15 (1990), 495–504, for the accusation of sociologism, and H. Collins and S. Yearley, 'Epistemological Chicken', in A. Pickering (ed.), *Science as Practice and Culture* (Chicago, IL: The University of Chicago Press, 1992), for the accusation of naturalism.

5. The dictum is that part of the sentence which is not modified by qualifying it, while the moving part is called modality: see Latour, op. cit. note 2, 60 (the directions of the diagram have been reversed for reasons of consistency), and B. Latour and S. Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press, 2nd edn 1986).

6. This is the 'first principle' of science studies: see Latour, op. cit. note 2, Chapters 1 and 3.

7. For a classical definition in structural linguistics, see O. Ducrot and T. Todorov (eds), *Dictionnaire encyclopédique des sciences du langage* (Paris: Le Seuil, 1972).

8. There are two definitions of a technical system. The first one, by B. Gille (ed.), *Histoire des Techniques* (Paris: Encyclopédie de la Pleïade, 1978), could be assimilated to a linguistic structure, but has never been demonstrated. The second one has been demonstrated by T.P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: Johns Hopkins University Press, 1983), but the structural effects are the results of the system builders' actions, not their cause. In neither case can the linguistic metaphor be implemented.

9. This is a limit of all second degree scientific instruments. An STG can be as good as a narrative, but not better. It is not acceptable criticism of a graph to allude to the dubious quality of the narratives it encodes.

10. One anonymous referee 'vehemently disagreed' with this wording, but offers another that is, in our view, strictly equivalent: 'maps should be used to get control of as much data as possible and to use this data to identify the key features'. Since a map is never a territory, as the saying goes, simplification is a necessary feature of instruments: see S.L. Star, 'Simplification in Scientific Work: An Example from Neuroscience Research', *Social Studies of Science*, Vol. 13 (1983), 205–28, and Star and J. Griesemer, 'Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907– 39', *Social Studies of Science*, Vol. 19 (1989), 387–420. For a bibliography, see B. Latour, 'Drawing Things Together', in M. Lynch and S. Woolgar (eds), *Representation in Scientific Practice* (Cambridge, MA: MIT Press, 1990), 19–68, and the other articles in this excellent collection. See also J. Law and G. Fyfe (eds), *Picturing Power: Visual Depictions and Social Relations* (Keele, Staffs.: Sociological Review Monographs, 1988).

11. Those of us who teach scientists and engineers badly need a simulator that would allow students to relearn the lessons of the many case studies studied by our field. The management games used in business school are ill adjusted to our teaching requirements, since the scientific information and the technical constraints played out in those games are not renegotiable. To enter many different case studies in a simulator, a common 'shell' has to be devised. We take STGs to be one small step in this direction.

12. For a more complete story, see B. Latour, 'Inscrire dans la nature des choses ou la clef berlinoise', *Alliage*, Vol. 6 (1991), 4–16.

13. We have been working for many years on a coding system that would automate the extraction of key words from a text. STGs may be fed either manually (as is the case here) or automatically by using the clusters obtained through Leximappe™ (see op. cit. note 3) and Candide™ (see G. Teil, *Une station de travail pour la sociologie des sciences [A Workstation for Bibliometric Studies in Sociology of Science]*, Thèse de Doctorat, ENSMP, Paris, 1991).

14. Actant means both 'action' and 'behaviour'. This term from semiotics is useful in spite of the criticisms (op. cit. note 4) because it does not oblige us to discriminate between humans and non-humans, and because it defines an entity only by the list of actions in which it is engaged.

15. Although this decision might seem arbitrary, there are ways to justify this reduction of grammar to semantics (see Teil, op. cit. note 13).

16. An 'antiprogramme' is every plan that is said to oppose a given plan. Like the word 'actant', it is a term from semiotics: see M. Akrich, 'Comment décrire les objets techniques', *Technique et culture*, Vol. 5 (1987), 49–63, and B. Latour, 'Where are the Missing Masses, Sociology of a Few Mundane Artefacts', in W. Bijker and J. Law (eds), *Shaping Technology—Building Society: Studies in Sociotechnical Change* (Cambridge, MA: MIT Press, forthcoming).

17. See Teil, op. cit. note 13.

18. The difference and the identity of any actant and of any project is defined, not by itself, but by its profile of associations and substitutions. One of the goals of STGs is to devise precise ways to determine degrees of identity and difference, and maybe to calculate them.

19. Synonymy is having the same profile of association, and the machine may be instructed to recognize it: see Teil, op. cit. note 13.

20. On the first principle of symmetry, see D. Bloor, *Knowledge and Social Imagery* (London: Routledge & Kegan Paul, 1976), and for the generalized principle of symmetry, see M. Callon, 'Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieux Bay', in John Law (ed.), *Power, Action and Belief: A New Sociology of Knowledge?* (Keele, Staffs.: Sociological Review Monographs, & Boston, MA: Routledge & Kegan Paul, 1985), 196–229, and also Latour, op. cit. note 2.

21. M. Coutouzis and B. Latour, 'Le village solaire de Frango-Castello: pour une ethnographie des techniques modernes', *Année Sociologique*, Vol. 36 (1986), 113–68, reports a real case rather like this theoretical solution: one of the observers claimed that he was building a solar village for the development of poor Cretans, while the other claimed that the first one was building a secret atomic plant for the benefit of the US Army. No wonder that the negotiation between the two parties was rather tense.

22. Classical social theory had a problem accepting the variable geometry of social actors, because it deemed all technical and scientific non-humans to be stable elements. When studying controversies or innovations, it is, on the contrary, often the case that

an actor modifies its scale ('IBM' becomes 'one of the members of the board of directors of IBM'), and its interests. As to the non-humans, we have learned to follow how they move from 'existence' to 'essence' and back: see M. Callon, 'Réseaux technico-économiques et irréversibilités', in R. Boyer, B. Chavanne and O. Godard (eds), *Les figures de l'irréversibilité en économie* (Paris: Editions de l'EHESS, 1991), 195–230.

23. On this crucial feature, see W.E. Bijker and T. Pinch, 'The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other', in Bijker, T.P. Hughes and Pinch (eds), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 1987), 17–50.

24. See A.J. Greimas and J. Courtès (eds), *Semiotics and Language: An Analytical Dictionary* (Bloomington, IN: Indiana University Press, 1982).

25. This is the main point of contention within SSK between actor-network theory and the sociological position. The latter believes it necessary to recognize in advance the essence of individual humans and collective persons, and to distinguish their action from the mere behaviour of natural objects. We believe that both essence and differentiation are the result of attribution work that can be studied empirically. On this dispute, see Collins & Yearley, op. cit. note 4, and the response in M. Callon and B. Latour, 'Do not Throw out the Baby with the Bath School', in Pickering (ed.), op. cit. note 4.

26. Anonymous referee; see also, on this example, M.E. Gorman and W.B. Carlson, 'Interpreting Invention as a Cognitive Process: the Case of Alexander Graham Bell, Thomas Edison and the Telephone', *Science, Technology, and Human Values*, Vol. 15 (1990), 131–64.

27. In addition, a very primitive form of inference engine may be built; the rules are not entered *a priori*, but are simply the representation of the contingent associations: 'if New key' is associated with 'Manfred + File', then 'System beaten'. It is important to maintain data in this form to turn STG into an interactive simulator. The player will be asked to try out new combinations, and will be limited by the 'rules' already learned. But since the rules are observer-dependent, it will be the task of the player either to 'interrogate' a new observer, to open one of the black-boxes, or to enter new data.

28. They may, however, still be elicited from the reading of the graphs: for instance, we can learn from Figure 4 that 'Tenants' were the antiprogrammes of version X1(1), since they enter the syntagm later; we can learn from Figure 7 that 'E' was in the anti-programme at version (2), since when it enters it requests the elimination of A and B; and so on. Such information might be the basis for 'rules' of association and dissociation.

29. Such variation is the basis of another possible use of STGs for management of complex technical projects. We ran two such case studies with the Innovation department of the French chemical concern Rhône-Poulenc: see Latour, Mauguin & Teil, op. cit. note 1.

30. See, for instance, the elaborate coding system developed by Gooding in order to follow Faraday's experimental process, in D. Gooding, 'Mapping Experiment as a Learning Process: How the First Electromagnetic Motor was Invented', *Science, Technology, and Human Values*, Vol. 15 (1990), 165–201.

31. See also Scott, op. cit. note 1, for other indicators.

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Geneviève Teil has recently completed her thesis on Candide, a workstation for the sociological treatment of large bodies of texts. She now works at CNAM in the Centre for Research in Ergonomics and Neurosciences.
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