INTRODUCTION TO GENERAL NET THEORY

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The aim of this course is to present a comprehensive framework which provides a firm formal basis for the numerous recent efforts to adapt the highly specialized theory of "transition nets" originated in 1960 to a wide range of applications.

Results of typical efforts of this kind will be presented during this course, especially from the area of computer science. Along with these presentations, a thorough introduction to the concepts and to the mathematical tools of a more general theory of nets will be given, in order to enable participants and readers to make effective use of the theory in existing and possible further applications, and also to view the diverse examples before a common background and in a single context.

By far the greatest part of current literature on nets [1] refers to "special net theory", as we shall call the above-mentioned restricted theory which is concerned with the flow of countable resources through nets, that is, through structures which resemble graphs, in which the various flows are on the one hand coordinated (e.g. synchronized) and on the other hand branched and merged. The interplay between synchronization and branching/merging may be graphically represented in a way which is easily understood by the non-specialist, and it permits numerical treatment of bottleneck- and deadlock problems and also of some questions about safety of operation and about conflict.

An informal but typical example for this stage of theory is given in Fig.1. It describes (part of) an arrangement as might be encountered in industrial production :

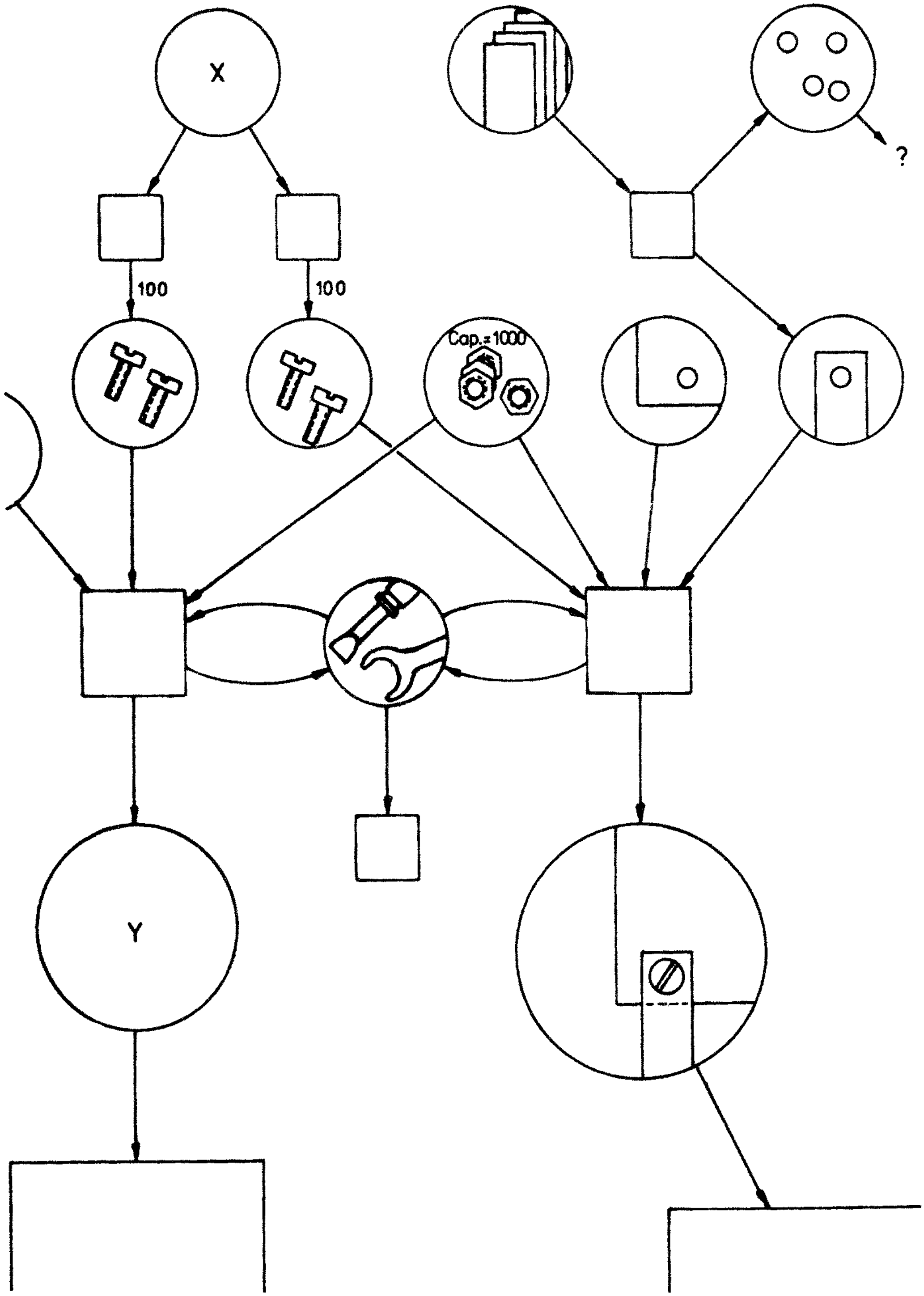


Fig. 1 :   A production schema

The rectangular □ symbols denote production activities such as transport, assembly or disassembly (example: punching); the circular ○ symbols denote places at which resources may be temporarily stored. The arrows → denote the directed relation of immediate accessibility; it is important to explain that they do not denote channels through which resources can flow; they are not assumed to have any material physical existence.

All □ ○ → symbols may carry inscriptions of a pictorial kind or taken from some formal or natural language. Some inscriptions relate the schema to real-world circumstances, others indicate the number of resources available at a place in an assumed case, or the number or resources needed in each instance of a certain activity, still others may indicate common features of distinct items or a detailed specification of an item.

In this way, special net theory treats a single net and the flow phenomena in this net, for each instance of application. Its practical limitations lie in the exclusive treatment of flow problems at a very low and detailed level. It is very difficult to even represent a net with thousands or millions of elements without making mistakes; it is practically impossible to explore the unknown behaviour of a system described in this way, or to verify all its intended behavioural characteristics by simulating and evaluating all processes which can occur in the system. Even with nets of less than 16 elements, one may have to give up understanding their workings by hand simulation. Nevertheless, the mere attempt to do so gives a basic understanding of the intricacies of concurrency and of local phenomena such as conflict and confusion. -

The development of general net theory was started in 1970 with the aim to overcome the limitations just mentioned. General net theory is not concerned with single nets; rather, the entities under consideration are relations between nets, operations and functions on the class of nets, transformations of nets, and most notably "net morphisms". Net morphisms are functions from one net into another which respect connectivity and orientation. They are of special interest in reasoning about systems and processes if they preserve other net properties as well, or if they interconnect very large and very small nets.

The following example is, at first sight, utterly trivial (Fig.2) :

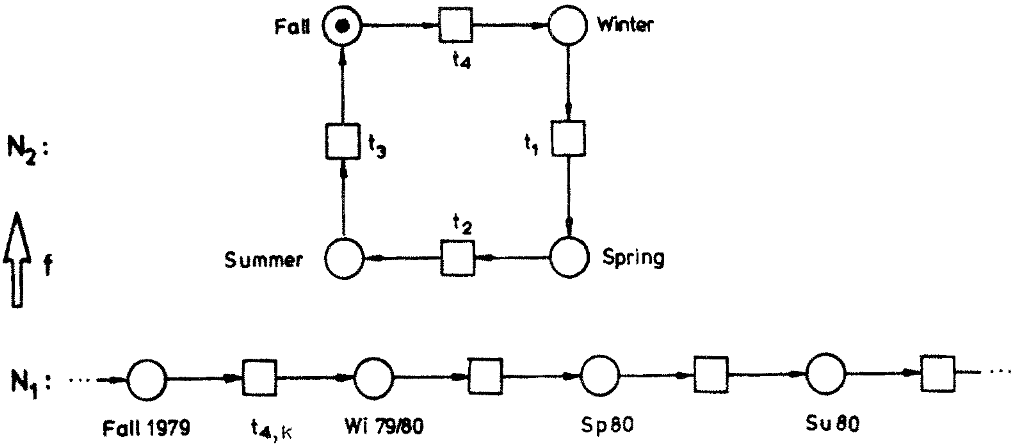


Fig. 2 : The change of seasons

The function f, a net morphism, maps the "very large" (infinite?) net of <u>occurrences</u> of seasons onto a "small" net which can be understood at a glance : $f : N_1 \longrightarrow N_2$.

Let us call the net elements denoted by ○ symbols "state elements" or <u>S-elements</u> and those denoted by □ symbols "transition elements" or <u>T-elements</u> .

Several conceptual and formal questions arise here, in spite of the apparent simplicity of the example :

1. The net N_1 (and therefore f) is not fully specified. We shall have to devise a means for recursive definition of nets; not restricted to this example, of course.
2. If N_1 is a chain of infinite length, it is just a mathematical construct which can be derived by "unfolding" the net N_2 , and is not an object of our experience. If we insist upon its reality, it means that we insist upon an eternal existence of the system N_2 , without beginning and without end.
3. If N_1 is to be a finite chain, we have to ask whether it begins resp. ends with an S-element or a T-element. (If N_1 is to be subjected to the same rules as the "condition-event-system" N_2 , its begin and end must consist of S-elements). The length of the chain then is either a matter of <u>observation</u>, or it expresses our <u>scope of concern</u>, as in the given example.
4. A typical occasion to extend our scope of concern arises when we shift our attention from the <u>elements</u> of a set X to <u>sets</u> of such ele-

ments, i.e. to the subsets of X. In doing so, we move to a different conceptual level, and the number of objects to be distinguished rises from n to 2^n. Therefore, if we define as "natural orders of magnitude" G_o, G_1, ... G_n ... by

$$G_o := G(o) := 0 \quad ; \qquad G_{n+1} := G(n+1) := 2^{G(n)} \quad ; \qquad g := G^{-1}$$

we have suitable milestones to describe one main purpose of net morphisms : to decrease or increase the scope of concern by an order of magnitude.

This is not obvious or compelling in the example of Fig.2; but $G_5 = 65536$ is surely a reasonable scope of concern for N_1, and $G_4 = 16$ for N_2. (In practice, there has never yet been occasion to use G_9).

5. The function f - once it is defined, along with N_2 - shall be called a <u>process</u> which can occur in the <u>system</u> N_2. N_1 is the <u>process domain</u> (of f); note that f may be defined by suitable inscriptions to the elements of N_1, but a chain without such inscriptions shall not be called a process; rather, it is the domain structure of many quite different processes.

6. Conditions such as "summer", "winter" etc. certainly have a <u>duration</u>, commonly speaking. What about the <u>changes</u> (transitions) between conditions? Do they also have duration? Depending on educational background, many different incompatible answers are given :
   a. All changes have a non-zero duration
   b. Changes take up all time
   c. All changes have zero duration
   d. All changes are states of uncertainty about the holding of conditions
   e. The concept of duration is not applicable to changes.

   Each of these opinions has been extensively used and defended, often with ideological vehemence. Net theory does not adopt one of these opinions a priori, but seeks to reconcile them by showing how they are interconnected and how a correct and useful part is contained in each.

7. The discussion of duration of changes is not mere hairsplitting, since its outcome <u>decides</u> the question how the apparatus of logic is to be applied to propositions of changing truth value; it <u>determines our logic of change</u> in this sense. Examples : If "winter" is recognized as a <u>condition</u> (propos. of changing truth value), does it comprise the transitions into winter and out of winter? We have indicated by the notation in Fig.2 that we choose to <u>define</u> the answer to be "no" : we want to talk of transitions as of enti-

ties in their own right, not just as of relations between conditions. This is a characteristic of the <u>approach</u> of net theory. But then the question arises : is "not-winter" also a condition in the system? If so, does "not-winter" comprise all four transitions $t_1 - t_4$, or just t_2 and t_3 , or no transitions at all? Is there a condition "winter or spring", "winter or summer", "winter and spring"? Are we justified in asserting that, within our scope of concern, it is "winter or spring or summer or fall" at <u>all</u> times?

Consistent answers to all of these questions, which have to be left open at this stage, will appear from a theory of <u>concurrency</u>, but not in terms of time-points and durations, which are not well defined concepts in the <u>operational</u> sense.

Net theory will treat times as clock readings, and will treat clocks on an equal footing with other system components : subject to malfunction and destruction, serving a purpose and requiring maintenance.

This non-idealizing attitude is also a main concern in the development of net theory : most assuredly for the sake of sound applications and not for philosophical reasons.

Let us sum up here all of the main concerns of <u>general</u> net theory, by listing the areas of problems to the solution of which this theory seeks to contribute :

A1	Interconnection between many conceptual "levels"
A2	Concurrency (partial independence of occurrences)
A3	Limitation of (all) resources
A4	Finding the most relevant concepts on each level
A5	Respecting imprecision of measurement, ubiquity of noise
A6	Bridging the gap between "discrete" and "continuous" models

<u>A1</u> will be topic of a separate section. The tool offered in this problem area is the category of nets, comprising all net morphisms.

<u>A2</u> will also need a separate section. Knowledge of the properties of concurrency is indispensable when constructing systems without central control or global observability of all details. The following example may illustrate the point. It shows an imperfect execution of a plan to extinguish a fire by carrying water from a remote source via a

bucket chain involving a number of people, even the general manager (since no central control is necessary for the execution of the plan) and the otherwise observing and theorizing scientist (no observation promotes the execution of the plan, under the given circumstances).

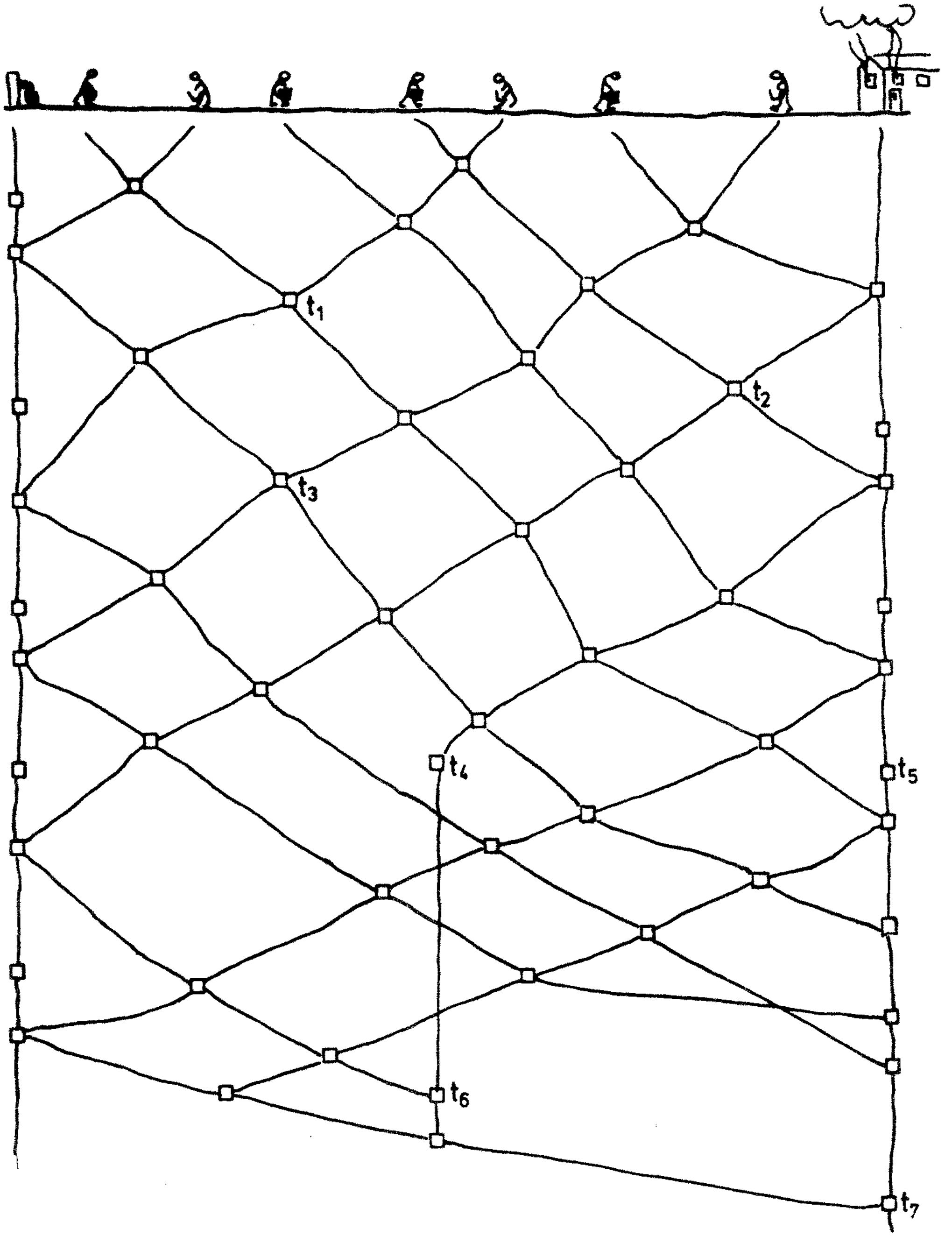


Fig. 3 : Partial history of execution of a plan

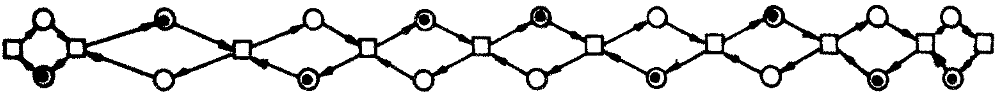
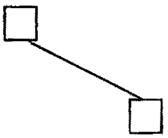
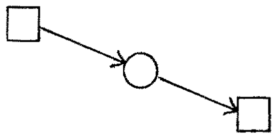


Fig. 4 :   The plan of which Fig. 3 is an imperfect execution

In Fig. 3, we have omitted the ○ symbols, and assume that all arrows point downwards :



is short for



The transition t_1 is an exchange of full and empty bucket; it affects two persons as role-players. t_1 is called *concurrent to* t_2 and vice versa, because there is no directed chain of arrows in the explicated net which links t_1 with t_2. We have t_1 co t_2 and t_2 co t_3, but *not t_1 co t_3*. *Concurrency is not transitive*. Observe that the smallest *meshes* in the net of Fig. 3 are shaped just like N_2 in Fig. 2, except for arrow directions; we shall say that they have the same *topological structure* as N_2 and shall give a definition of *net topologies* in such a way that they form a basis for making progress in problem area A6 above (bridging the gap between "discrete" and "continuous" modelling). This can be done only after giving a formal definition of nets. Suffice it to state here that net morphisms are defined after the model of *continuous functions* in the sense of topology.

At t_4, a deviation from the ideal plan occurs. Assume that the scientist, unaccustomed to the activity of really helping where help is needed, drops unconscious. This does not matter much since a) in the example, he does so concurrently to the extinction t_5 of the fire, and b) the system of a bucket chain is, to some extent, self-mending : a smaller plan of the same structural type as the original one continues to be executed, without change in conventions. Anyway, he is given first-aid at t_6, and everybody is safe home again after t_7.

Note that the meshes of the net in Fig. 4 are smaller than those in Fig. 3. But clearly, there is a morphism f which maps the "regular" part of the net in Fig. 3 onto the net of Fig. 4. Again, f is called a process. A current state-of-affairs (initial, for Fig. 3) is depicted at the top of Fig. 3; the image of this *case* is indicated by markings, or *tokens*, on the S-elements of Fig. 4. -

The fact that all resources are limited should be recognized by every realistic theory of systems and processes (A3). This goes without saying, and becomes tautological if we define "resources" as those entities which can, by being scarce in a given situation, impede the reaching of a goal. Energy, materials, manpower are obviously resources. Time and space are also often referred to as resources, and rightly so, though not in a formal sense. Net theory seeks to go a step further by taking the "resource-type" character of space-time as fundamental and constitutive for the space-time concept. Final results of this approach do not yet exist, but the spirit of the approach should be kept in mind when translating classical system descriptions into net-theoretical ones. It should not be regarded as a defect of net theory that some geometrical and kinematic concepts are not readily expressed in terms of nets.

Rather, information will be the resource of main interest in net theory, because its usage is more complex and much more general than the usage of other resources; indeed, information usage is a prerequisite of usage of other resources, but little is known about it. We do have e.g. hydrodynamics and electrodynamics in a satisfactory degree of perfection, but no remotely comparable "information dynamics". To indicate the approach of net theory in this respect, we state here that we shall treat (define) information as that kind of resource which is used to resolve conflicts. We shall introduce formally an "axiom of local determinacy"; to the extent this axiom is valid in the world we live in, we are able to assert that "information is always somewhere but never everywhere" as a basic relation between information and space-time.

It is a point of special importance that the absence of certain entities or phenomena (in a given context) is also to be treated as a resource. This point has first been recognized in full depth by Anatol HOLT. Obvious examples are the absence of toxic substances in a biological context; absence of noise for ideal transmission of messages; also, the whiteness of paper (absence of previous printing) makes such paper a resource beyond the availability of paper material. But many resources of this kind are hidden to the untrained mind and do not yet have a name. E.g. several different resource types which fall under the heading "omission of an activity" have to be distinguished because they have different properties. -

Relative to a given goal, some resources appear to be unlimited in supply. In classical logic, in pure mathematics and in part of computation theory, the supply of "white paper" and of time is (implicitly) taken to be unbounded; from the standpoint we take in net theory, this means precisely that shortages of these resources are outside the scope of concern of those scientific activities, in the sense we have used when discussing Fig. 2. Note that in computation theory, the scope of concern has been narrowed down in this way just in order to detect the limitations of another "resource" : computability. Once this goal has been achieved, the proper thing to do is to shift or to widen again the scope of concern. (Again, the development of computation theory is an example that this is being done).

A final remark about resources : It is not true that limitation of resources is just a fact to be deplored. In everyday-experience as well as in net theory, we find many examples that scarcity of resources may have an advantage. Its impact on the choice of more realistic goals is only a superficial, though important, aspect; the reader can easily find more specific examples. Abstractly speaking, the artificial well-structured limitation of resources is one of the main tools to establish an organization - possibly the only one. -

Re A4 : Finding the most relevant and appropriate concepts on each level of process or system description, is a task which cannot be readily explained without doing it. We use the word "level" in an informal sense only. We recognize that the notion of an objective arrangement of lower and higher levels of thinking into a series is not a sound one, but is sometimes helpful in teaching.

In this spirit, Fig. 5 should be regarded as intuitive and somewhat arbitrary, except that we shall provide a sequence of formal constructions from level 0 up to level 3 and beyond. These constructions can serve, in a general way, as a schema for stepping up to "higher" levels, and for analysing and defining (vague) higher-level concepts in terms of lower-level concepts.

We regard a concept of some level as appropriate if it is related in an understandable and precise way to the concepts of neighboring levels. Therefore, a concept can be called "appropriate" only relative to the chosen structuring of levels.

Levels 4 to n-2 refer to computer science matters, level n-1 to administrative and business matters where organizations and procedures are fairly well defined, at least for the modest purpose of mere description.

The concepts of channel, agency, role and activity named at this level have been chosen in such a way that it becomes possible to go far beyond description on this level. Again, this can be done only by recognition of at least one additional level n .

Level number:	Typical concepts:	
n:	Interests (of groups, individuals...)	Restrictions (natural, legal, economic...)
n-1:	Channels (for resources, messages...)	Agencies (institutions, offices...)
	Roles (of people, artefacts...)	Activities (belonging to each role)
n-2:	Global reliability	Performance
n-3:	Data bases	Computer architectures
. . . .	. . .	
	Protocols	Operating systems
	Files	Tasks
	Records	Statements
	Machine words	Machine instructions
. . .	if, and, assignment, identifier, value ...	
4:	NAND-gates , delays , clocks ... transistors , diodes , oscillators ...	
3:	"Stations","flux" ; (as used in low level information flow graphs)	"Transfers","influence"
2:	Conditions Synchrony (as used in condition-event systems and transition nets)	Transitions "Enlogy"
1:	Occurrences and their partial order in time (Occurrence nets)	
0:	Concurrency structures ("ropes")	

Computer Science

Fig. 5 : A sequence of conceptual levels concerning computer science, its foundations and certain applications

The fact that precision and explicitness are not always welcome on level n (with regard to interests, intentions, recognition of restrictions) puts a definite limit to useful formalization on level n-1 and, at closer inspection, on all lower levels. For the rest, it can observed in Fig. 5 that with increasing level number, our classical formal tools become less and less useful or successfully applicable.

While on the subject of concepts and formalization, we cannot proceed without a bit of formalism : the concepts named in Fig. 5 have been chosen, wherever possible, such that they can be related to the carrier sets S and $\boxed{T}$ of a net.

A net can be defined in many structurally equivalent ways (see the Dictionary in these proceedings). We chose the one which is used most in the literature. A triple (S,T;F) will be called a net, iff S and T are disjoint nonempty sets with a relation F between them such that every element of S and T occurs in the relation F :

Net (S, T; F) :$\Longleftrightarrow$	
1.	$S \cap T = \emptyset$
2.	$S \cup T \neq \emptyset$
3.	$F \subseteq (S \times T) \cup (T \times S)$
4.	$dom(F) \cup cod(F) = S \cup T$

Fig. 6 : The (S,T;F)-form of a net

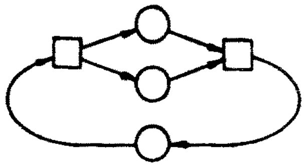
Note that it follows from Fig. 6 that both S and T are non-empty, that F is non-empty, and that no element of S or T is isolated in terms of F .

Examples : Every directed multigraph is a net (S,T;F) = (Arcs, Vertices; Incidence-relation) iff it has no isolated vertices.

$(S,T;F) = (\mathbb{R},I;F)$ is a net where $\mathbb{R}$ is the set of real numbers, I the set of finite connected open intervals over $\mathbb{R}$, and

$$(r,i) \in F \;:\Leftrightarrow\; r \in \mathbb{R} \wedge i \in I \wedge \bigvee r' \in \mathbb{R} : i = \{x \mid r < x < r'\}$$
$$(i,r) \in F \;:\Leftrightarrow\; i \in I \wedge r \in \mathbb{R} \wedge \bigvee r' \in \mathbb{R} : i = \{x \mid r' < x < r\}$$

A non-example : A net is not a bipartite graph because the triple (S,T;F) is ordered : S and T play different roles. If (S,T;F) is a net then (T,S;F) is also a net, but a different one, and not necessarily isomorphic to (S,T,F) , as with the nets



and

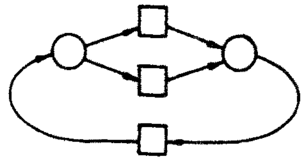


Fig. 7 Fig. 8

which are called duals of each other; whereas the bipartite graph (F, $\{S, T\}$; incidence-relation) is the same for both nets.

The reason we have to insist that nets are not structurally equivalent to bipartite graphs is this : Once we have chosen to associate S-elements with the concept of "state" and T-elements with the concept of "transition" as in our first example (Fig. 1), we have no longer a choice how to associate other suitable pairs of mutually "dual" concepts with S and T ; e.g. chemical substances (elements or compounds) and chemical reactions can be consistently associated with S and T in this order. When we form new pairs of concepts such as "channel" and "agency" (for analysing organisatorial problems), the way to classify them under S resp. T carries an essential part of meaning and is a prerequisite for establishing the conceptual interconnection between neighboring levels within one science, and also for the transfer of structural knowledge between different sciences.

Net theory is mainly concerned with computers and information handling, but has drawn many ideas about structure and organization from other areas, mainly from areas where computers are applied: Fig. 9. Some feedback to those areas has occurred (see [1] and these proceedings); much more of this interdisciplinary transfer is under investigation.

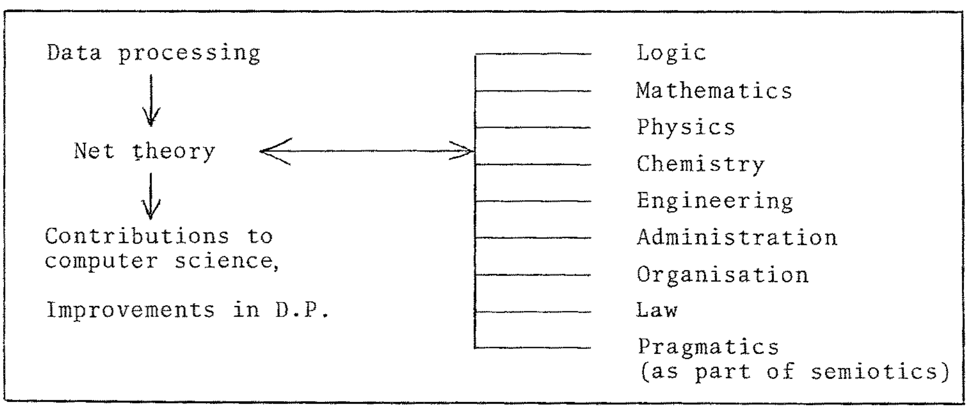


Fig. 9 : Evidenced interdisciplinary connections of net theory

An application of net theory in some area starts with a choice of a triple of concepts which satisfy the net definition in (S,T;F) form, Fig. 6. E.g. when we begin to apply net theory to organizational problems, we may describe a specific organization as a set of agencies (T) communicating (F) over channels (S) . In the following table Fig. 10, we give a list of fairly well established concept pairs (S,T) which are suitable for this purpose. The meaning of the corresponding relation F is not given in the list. It is easy to find when the meaning of S and T is understood, but often difficult to verbalize concisely.

	S	T
o	state-elements	transition-elements
1	states	transitions
2	conditions; "places"	events
3	conditions	facts
4	open singletons	closed singletons
5	structural types	constructions
6	log. statements	dependencies, deductions, proofs
7	chem. substances	chem. reactions
8	languages	translators
9	stations (in information flow nets)	transfers
1o	product types	production activities
11	countries	boundaries
12	channels	agencies
13	(organizational) roles	activities
14	pragmatical status (of messages)	pragmatical transformations
15	functional units for the representation of data	functional units for the processing of data

Fig. 10 : Some concept pairs for applying net theory

The entries in the list Fig. 10 are in arbitrary order, numbered for reference only. They are not intended to show that net theory has many and diverse applications : a comparable list for graph theory might have hundreds of entries. Rather, all entries of concepts are <u>closely interrelated</u> by net theory : e.g. knowledge about condition-event-nets yields definite useful rules for the analysis of channel-agency nets. Another example : the existence of a "1-mesh"

, $F \cap F^{-1} \neq \emptyset$

as a subnet of a given net means

in chemistry : s is a catalyst in catalytic reaction t

in logic : t is a tautology containing „$s \Rightarrow s$"

in mathematics : t is a theorem about the structure class s

in condition-event-systems: s or t is not atomic

in graph theory: a selfloop exists at vertex t

in pragmatics : the change in pragmatical status of messages in s by t is neglected. (t might be a READ or COPY operation)

So we can learn about pragmatics by studying the theory of catalytic reactions, learn about catalytic reactions by studying the logic of change, etc. From some connections we cannot learn much, but in principle always something.

The concept pair "data/processing" is not in the list because it has many facets. Some of these facets are subsumed in the entries 2, 3, 5, 6, 8, 9, 10, 12, 15, and - most importantly - 14.

To assign a <u>pragmatical status</u> to each instantiation of a piece of "data" is useful and appears to be necessary to establish a strict bond between <u>messages and purposes</u>. This bond is well acknowledged and respected e.g. in banking and in the handling of "sensitive" data, but not in a formal sense. A pragmatic status can be described as a place where messages can reside; the input and output transitions denote the activities by which a message can enter resp. leave that place. In genaral, such activities do not consist in a mere transport of one message from its pragmatic status into a new one; rather, they consist in transforming a bundle of messages belonging to one another into a new bundle. E.g. an order is not transported correctly from the status "to be executed" to the status "executed" without doing something else in that same act. The simplest feature immediately expressed in a pragmatic net is <u>accessibility</u>, through the relation F . Accessibility can mean a legal right to access, or the physical possibility of access. The next step for developing a useful formal calculus for pragmatics is, to express legal rights in terms of physical possibilities. This can be done by employing the formalism of "multiple enlogic structure" through the distinction of legal cases, illegal cases and non-cases. We shall not follow this up here.

A5 and A6, the problem areas at the end of our list, are closely connected. In a good modelling technique, imprecision of measurement should be respected from the beginning. Concerning net theory, we take the standpoint that this imprecision is not only a consequence of our poor abilities to distinguish by direct or indirect observation, but that it is inherent in the nature of the measuring process itself and in our relation to the objects we measure. We regard measurement processes not as basic to the theory and not as lying outside of the theory, but rather as complicated processes of information flow, influenced by noise, i.e. by unaccounted-for information; and we enquire into the combinatorial structure of these processes. Also, we have reason to propose, as a result of this enquiry, a new type of measuring scales [2] which has a bearing on the treatment of measurement results.

We shall respect the presence of noise to the greatest possible extent : all information flow nets (level 3 in Fig. 5) will be constructed exclusively from "noisy channels" for transmission of bits. The concept of "noisy channel" can be explicated by a net morphism on level 2 (of Fig. 5) in terms of conditions and events, as an injection of intended transmission into physically possible (noisy) transmission :

$$\text{sender} \xrightarrow[\text{channel}]{\text{noise}\ \downarrow} \text{receiver}$$

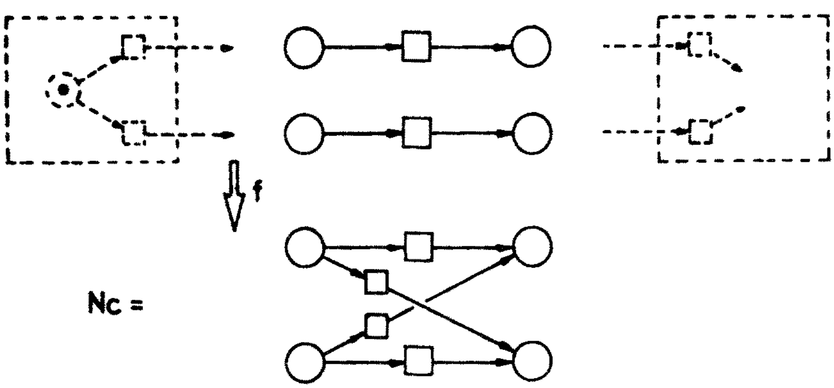


Fig. 11 : Explication of "noisy channel"

All level 3 nets will be composed (by quotient formation) out of level 2 nets of the structure of Nc (in Fig. 11); they are operationally equivalent with the class of all distributed, self-synchronizing binary switching networks with memory. Nc can also be described as a 4-mesh with the same topology as the cycle of seasons (Fig. 2) :

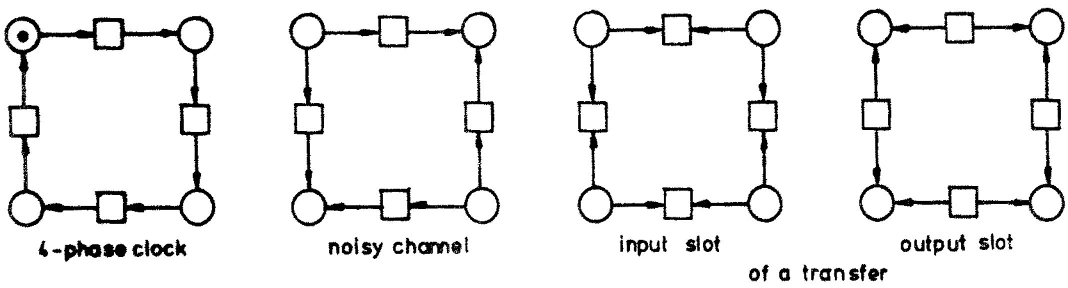


Fig. 12 : Meshes for composing level-3 nets

Slots will be explained elsewhere in these proceedings.

Re A6 : As a final problem area for net theory we mention the striving to bridge the gap between so-called discrete and continuous types of modelling (Fig. 13).

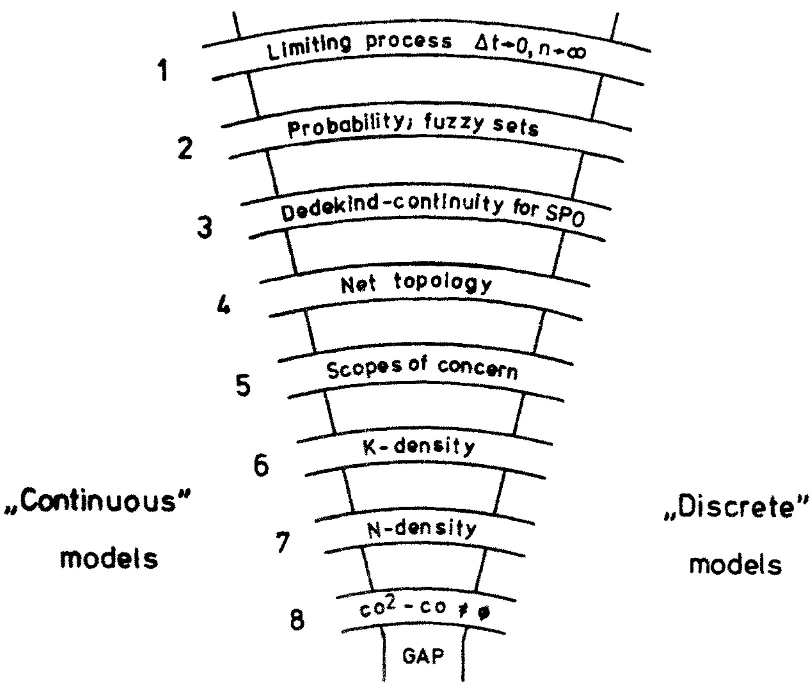


Fig. 13 : Bridges between continuous and discrete models

Level	abstract 0		1		2	3 ... n	applied 2... n
Primitive Concepts	$\mathbb{C}$ co (concurrency), resp. (= class of maximal sets of pairwise coexisting elem. phenom.)						$\mathbb{W}$ "real world"
Defined Concepts	occurrence, condition, event, cut; state, transition, proximity, case;		rope, net;		flow; CE-Net	CA-Net	System Model
Axioms		Coexistence Axioms		Extensionality Axiom		Local Determinacy Axiom	GNT - Hypothesis: $\mathbb{C} \rightleftarrows \mathbb{W}$
Structures, Models of	Elementary Phenomena		Histories Processes Scales		Condition-Event-Systems		Systems with general components in their environments
Mathem. Definitions Theorems Methods formal Axioms	set theory	Rope defin. Net defin. History - process axioms in terms of nets	Theorems on histories and processes	Net morphisms category of nets Net topology	Synchronic structure Enlogic structure	Properties of information flow: flux, influence	General Net Theory
Typical questions treated			concurrent and sequential action scale construction		repetitive and alternative action synchrony measurement		conditional and decisional action information flow resource management

Fig. 14 : Outline of General Net Theory

Bridges 1 and 2 are the well-known classical ones. They span the gap where it appears widest, so they are difficult to cross. Net theory has, up to now, built six additional bridges 3 - 8. It remains to be seen how much load they can carry. They are strict formal constructs, presented here in an informal way. Giving up the assumption that concurrency is transitive when a process description is sufficiently detailed (bridge 8) takes a single inconspicuous formal step, and is a matter of course in relativity theory. Yet it appears to be a most difficult step to many workers in other fields, and is often violently attacked. We shall content ourselves, in this course, with pointing out the formal consequences of this step, to the extent that they seem important for past and future applications.

In conclusion, we give without further explanation the present status of the conceptual framework for the development of general net theory : Fig. 14. It might serve to guide the reader through the formal aspects of the material presented in this course; it should be revisited after taking notice of this material.

The aim of this introduction has been to sketch in broad strokes the landscape of net theory. It reflects the perspective with which the author wishes to view this theory and its applications. In the body of the introduction, results have been claimed but the claims have not been substantiated. Concepts have been named but they have not been sufficiently explained. These matters will be attended to in the course material proper. But beyond this, this introduction may have raised a mixture of high hopes and grave doubts in the mind of the reader. He should be aware that a long hard road with many bends and pitfalls will have to be traversed before these hopes can be fulfilled and the doubts dispelled. Our introduction is to be viewed as an invitation to the reader to join in the undertaking of this difficult journey.

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