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The Use of simulation in an Operator Companion for a Nuclear Power Plant

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SUMMARY

We have been investigating the integration of symbolic computation into highly computerized numerically-based real-time simulation and control for complex plant process management. This is the natural next step in an evolving maturation of the use of computers for automated monitoring and control of continuous processes. A particular implementation involving nuclear power plant intelligent monitoring is being developed from which overall principles and specifications can be distilled, ultimately leading to a general methodology that can be applied to other continuous plant processes.

Key factors addressed under such a system are 1) the design of a distributed system and control strategy best suited to handle continuous massive amounts of information generated in complex plant processes under the constraints of real-time requirements; 2) the optimization of communication procedures which integrates a society of processing engines (real-time simulation, data acquisition, trend analysis and knowledge processing) into a responsive and reliable system working towards a common goal; and 3) the creation of an intelligent management system which accommodates incremental growth in numeric and symbolic components without jeopardizing real-time capabilities.

We have begun a study of both loosely and tightly coupled hardware configurations, with a central symbolic processor as master. Real-time capabilities are maintained through the use of satellite processors communicating via blackboard techniques which include a temporal component for large range trend analysis. Possible hybrid combinations of processing elements are also under investigation.

ABOUT THE AUTHORS:

For the last five years, a small research group at McMaster University in Canada, has been active in applying expert system techniques to real-time systems.

Dr.Wm.Garland, Associate Professor and Chair of the Department of Engineering Physics, has focused research on designs for large nuclear power plant operator companions with particular emphasis on using the blackboard paradigm to reduce real-time acquisition data to manageable levels while providing an interprocessor communications media which promotes data concurrency via this information hiding structure [1]. Decade based time slicing is used to reduce the data to be handled by many orders of magnitude. Trend analysis is by neural network paradigms and real time thermalhydraulic and reactor physics simulation is implemented by parallel engines and advanced numeric algorithms that permit large timesteps. Actual implementations are to be carried out initially within McMaster's own nuclear research reactor using a loosely coupled processing structure. Primary funding agencies include the Natural Sciences and Engineering Research Council of Canada and contracts with Ontario Hydro and Atomic Energy Canada Ltd. Dr.Garland has had extensive experience in nuclear power plant design and simulation [2,3,4]. AI projects include computational algebra [5] and Expert Systems for the selection and design of industrial heat exchangers [6].

In concert with this work, his colleague, Dr.W.F.S.Poehlman, Assistant Professor in the Computer Science and Systems Department, has generated several smaller knowledge-based control systems within the McMaster University Tandem Accelerator Laboratory. Here, operating companions have been generated for a range of accelerator operators employing an enhancing procedure termed user modelling. For real-time control aspects, temporal abstraction in the form of a two-tiered processor architecture has been employed. Of particular difficulty is the algorithmic/heuristic decoupling procedures necessary to determine the duties of the two levels. This was further complicated by inclusion of traditional software structures such as spreadsheet analysis and database operations. Work is proceeding on the incorporation of an Expert System Interface Language to operate in the real-time processors for the isolation of site customization form more global operating procedures which are more the purview of symbolic processors. Also, neural processing paradigms are being integrated into expert system processing to reduce data influx via appropriate (and dynamic) data stream filtering. Funding for these investigations are occurring under contracts with the Canadian Department of National Defence and the Telecommunications Research Institute of Ontario (a provincial Centre of Excellence). Dr.Poehlman has been active in developing real-time systems for research prior to entry in the academic arena.

EXTENDED ABSTRACT

Human expertise (inherently symbolic or pattern recognition based) must be married to the speed and pervasiveness of computerized data acquisition, trend analysis and simulation which all reside more in the domain of numeric processing.

Herein we investigate the integration of symbolic computation and reasoning into highly computerized numerically-based real-time control systems for complex plant process management. The particular implementation involves nuclear power plant intelligent monitoring and the development of suitable subsystems that are required for the Operator Companion.

A beginning thrust has already been made with the development of several subsystems components. The main expert system includes an alarm pattern analyzer (which currently recognizes 58 minor alarms and 15 major ones) based on Intellicorp's KEE32 and a Texas Instruments' Explorer3-I LISP machine, a simulation model of a nuclear reactor and thermalhydraulic processes employing a computer-aided computational algebra subsystem, a trend analyzer focussed on the CANDU primary heat transport system as well as a rule-based satellite expert system tuned for early detection of a major loss-of-coolant accident. The components are illustrated in figure 1.

The combined goal of these systems is ultimately to contribute to the development of an operator companion which is knowledge-based that can assist the nuclear power plant operator to quickly diagnose faults and abnormal conditions and to respond to them in a timely and appropriate manner.

We envision a central control strategy in which the expert system is the system master. Moreover, this master utilizes high level information provided by satellite processors (involved in data acquisition, trend analysis and simulation). These subprocessors can be symbolic or numeric in nature as required. Off-loading the master processor via the subprocessor configuration can potentially resolve many problems imposed by real-time performance and provide the high level arbitration capability needed. However, the resulting distributed systems now require that significant attention be paid to a suitable communication strategy to be effective.

The blackboard concept plays a major role in providing the required functionality in communication and the blackboard itself is amenable to implementation on a separate processing engine. Although utilized primarily as a global structure to promote cooperative problem solving amongst a group of independent knowledge sources, we believe this strategy is useful for both numeric and symbollic information passing. As with the original implementation, it provides advantages of modularity and flexibility where the restructuring of the system is easily accomplished while allowing various control strategies to be explored.

In our implementation, the blackboard contains semaphores (flags) to generically link the individual processors and the real-time information that has been collected by the data acquisition system and massaged by the trend analyzer. In particular, the blackboard provides the means to compare the trend analyzer with the shadow simulation, thus highlighting areas of concern.

The trend analyzer observes trends typically on the order of seconds, minutes, hours or even months. This allows the identification of problems of high frequency through to slow deterioration. To detect deviation, a baseline is, of course, necessary. Hence, the trend analyzer consists of a data storage section (time slice snapshots) and a generic numeric/symbolic calculation section for computing expected values, setting indicator flags, etc.

The Operator Companion is composed of (1)an alarm pattern analyzer as a major component of the main expert system, (2)a data acquisition subsystem, (3)a trend analyzer, and (4)a satellite expert system whose main focus is the primary heat transport system of the reactor. The plant simulator augments the satellite expert system.

The work completed to date shows that the overall concept appears sound and should be pursued.

The simulator utilizing the rate form of the equation of state is efficient and robust. Future developments should include implementation of station control, thermalhydraulic correlations and I/O interfacing. The trend analyzer, simulator and expert system need to be integrated into a cohesive whole.

The short term goal of this work is the demonstration of the viability of an Operator Companion running on the McMaster Nuclear Reactor, prior to its implementation at CANDU stations.

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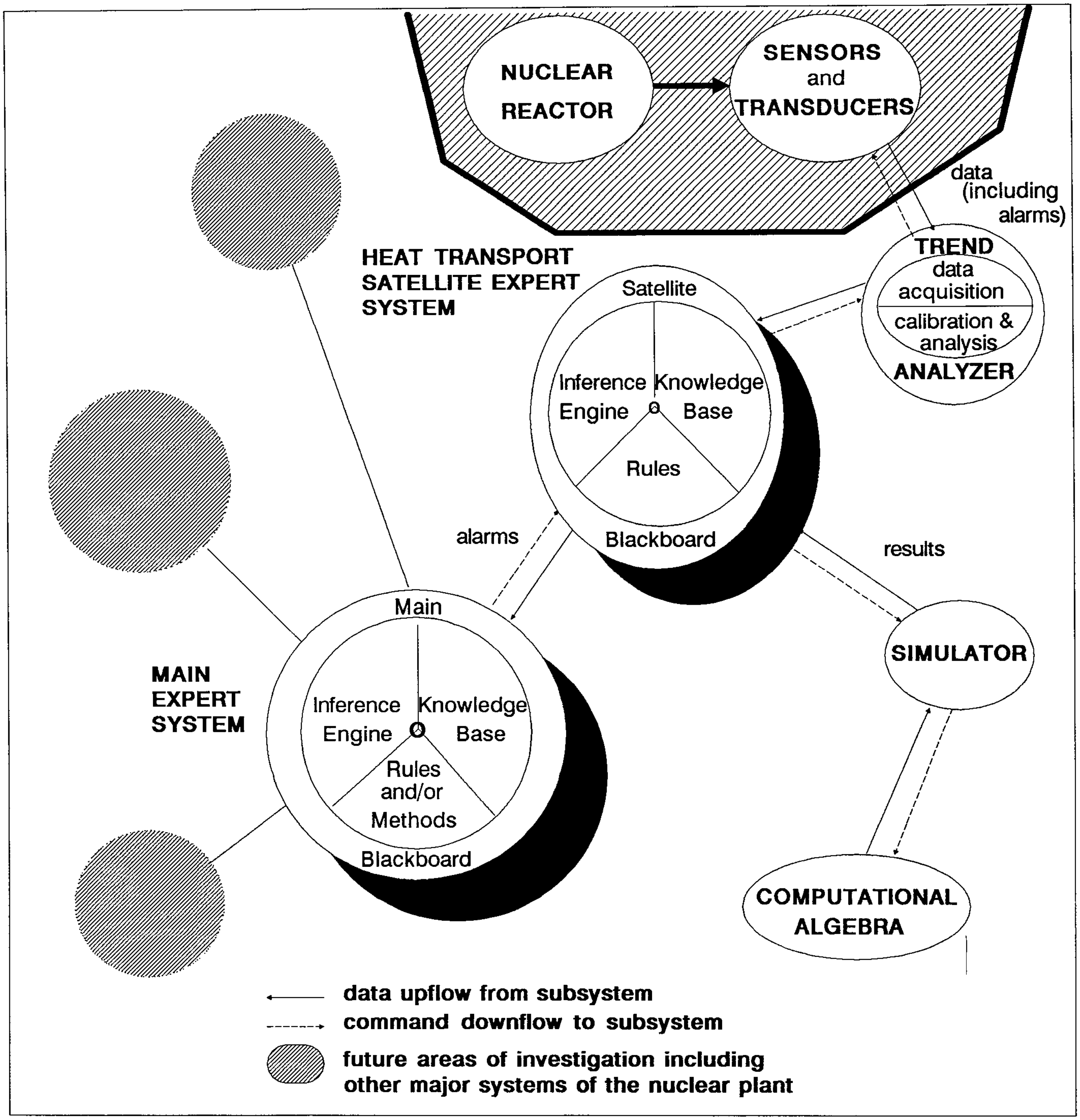

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AI & Simulation

A Real Time Application

- Not a scenario analyzer

- Is a knowledge-based system to support real-time processing systems

- Will discuss an expert system (Nuclear Reactor Operator Companion) focusing on the architectural design strategy

- Main points of discussion:

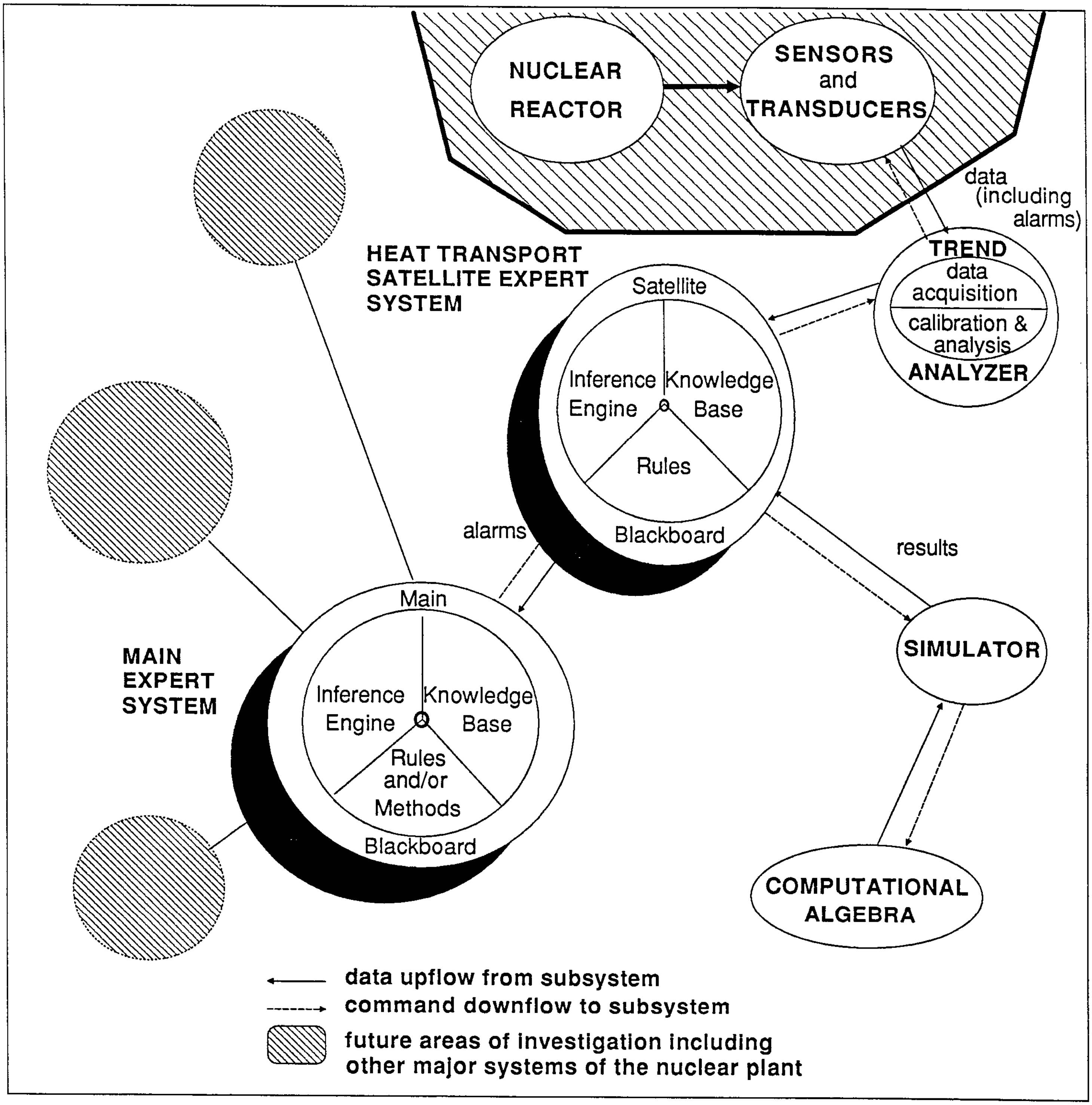
    problem definition -> finite vs. infinite

    inference strategy -> procedural vs. declarative

    inference tactics -> exclude + score card

Overview of the Operator Companion

- **Purpose of companion (problems faced by human operator)**
- **Role and concept of each component**
  - **reactor**
  - **blackboard**
  - **trend analyzer**
  - **data acquisition**
  - **simulator**
  - **satellite expert system**
  - **main expert system**
- **Data flow**
- **Layering (functional abstraction)**
  - **low level numerics vs. high level symbolics**
- **Time slices (temporal abstraction)**
- **Blackboard - to present and compare time slices**



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Problem definition -> finite vs. infinite

- It's all in how you pose the question.

- Example:

Is there a problem?
-> must search an infinite problem space
therefore not bounded in time

Is there a small Loss of Coolant Accident (LOCA)?
-> A small LOCA is one object to be investigated.
All potential problems that the operator needs to
monitor are explicitly identified.

Inference strategy -> procedural vs. declarative

- Use declarative inference engine only if goal changes.

- For the operator companion, the goal is to identify the presence of a problem from a finite set of possibilities.

- Thus can use a procedural approach.

- Using a layered approach:

- Lower level (simulator, trend analyzer) is numerically intensive
  -> use procedural approach

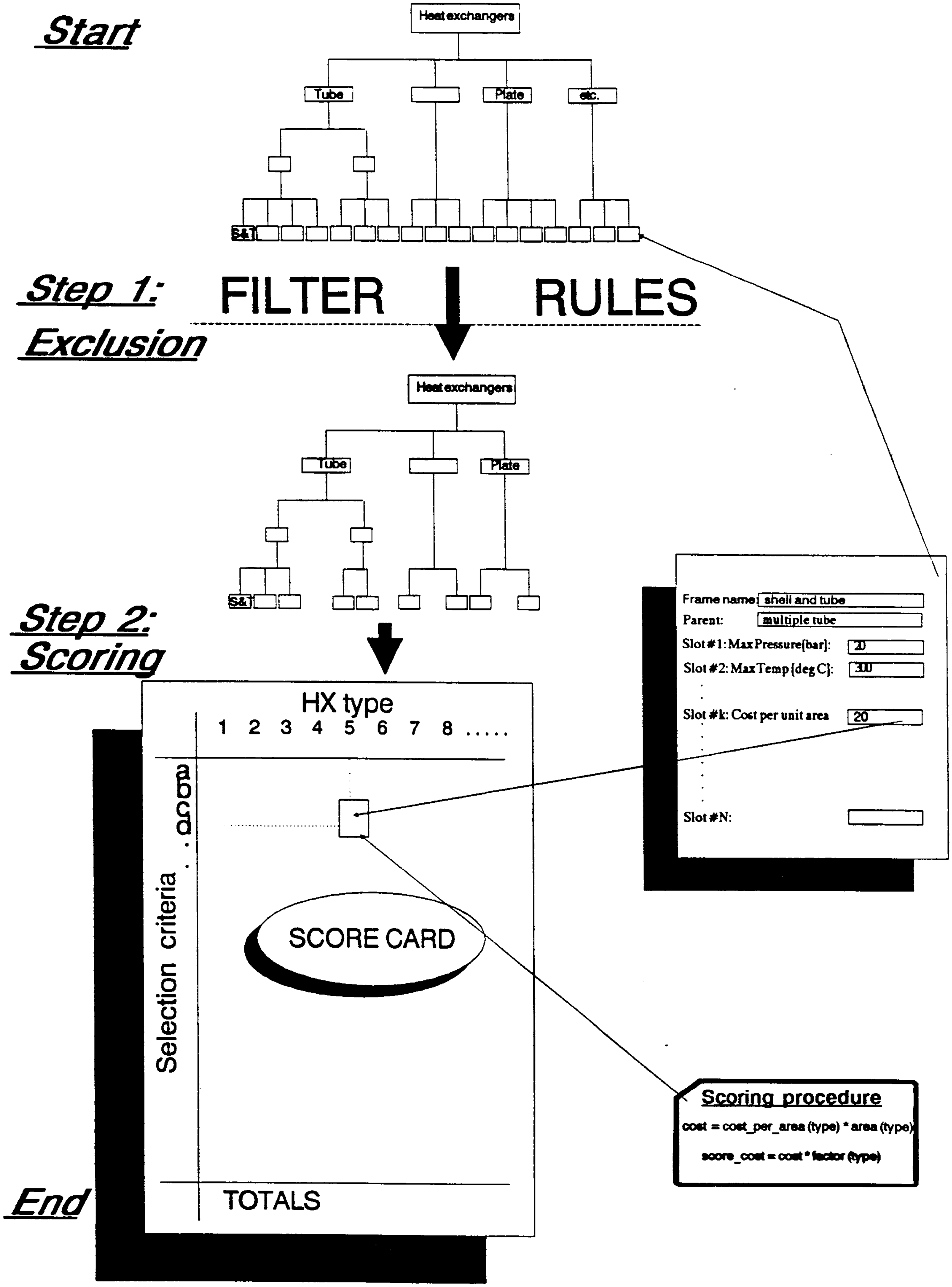
- Higher level (ES) is symbolic and is dealing with less information with reduced time constraints

  -> declarative OK

Inference tactics -> exclude + score card

- **Example of exclude and score that has been successively implemented:**

  heat exchanger selection


Start
Heat exchangers
Tube
Plate
etc.
S&T
Step 1:
FILTER
RULES
Exclusion
Heat exchangers
Tube
Plate
S&T
Step 2:
Scoring
HX type
1 2 3 4 5 6 7 8 .....
Selection criteria
a
b
c
d
SCORE CARD
TOTALS
End
Frame name: shell and tube
Parent: multiple tube
Slot #1: MaxPressure[bar]: 20
Slot #2: MaxTemp [deg C]: 300
Slot #k: Cost per unit area 20
Slot #N:
Scoring procedure
cost = cost_per_area (type) * area (type)
score_cost = cost * factor (type)

Exclusion

- In general, a few process signals can be used to confidently conclude that certain problems do not exist.

- Example:

  IF power > 25% THEN EXCLUDE reactor trip

  IF rate of change of power < 1% / sec THEN EXCLUDE reactor trip

- The problems that are left on the list (ie are still possibilities) are ranked via a score card. (see figure)

- The difference between this and the heat exchanger case is that the objects here are not similar enough to have a common scoring base

- What would the scoring procedures be?

	ATTRIBUTES			
PROBLEM	surge tank level	surge tank pressure	ROH pressure	...
LOCA a				
LOCA b				
.				
.				
.				
LOCA F				
Reactor trip				
Turbine trip				
.				
.				
.				

(attributes include all signals and their averages)

Scoring strategy

- Do in stages:

first discriminate between classes of problems

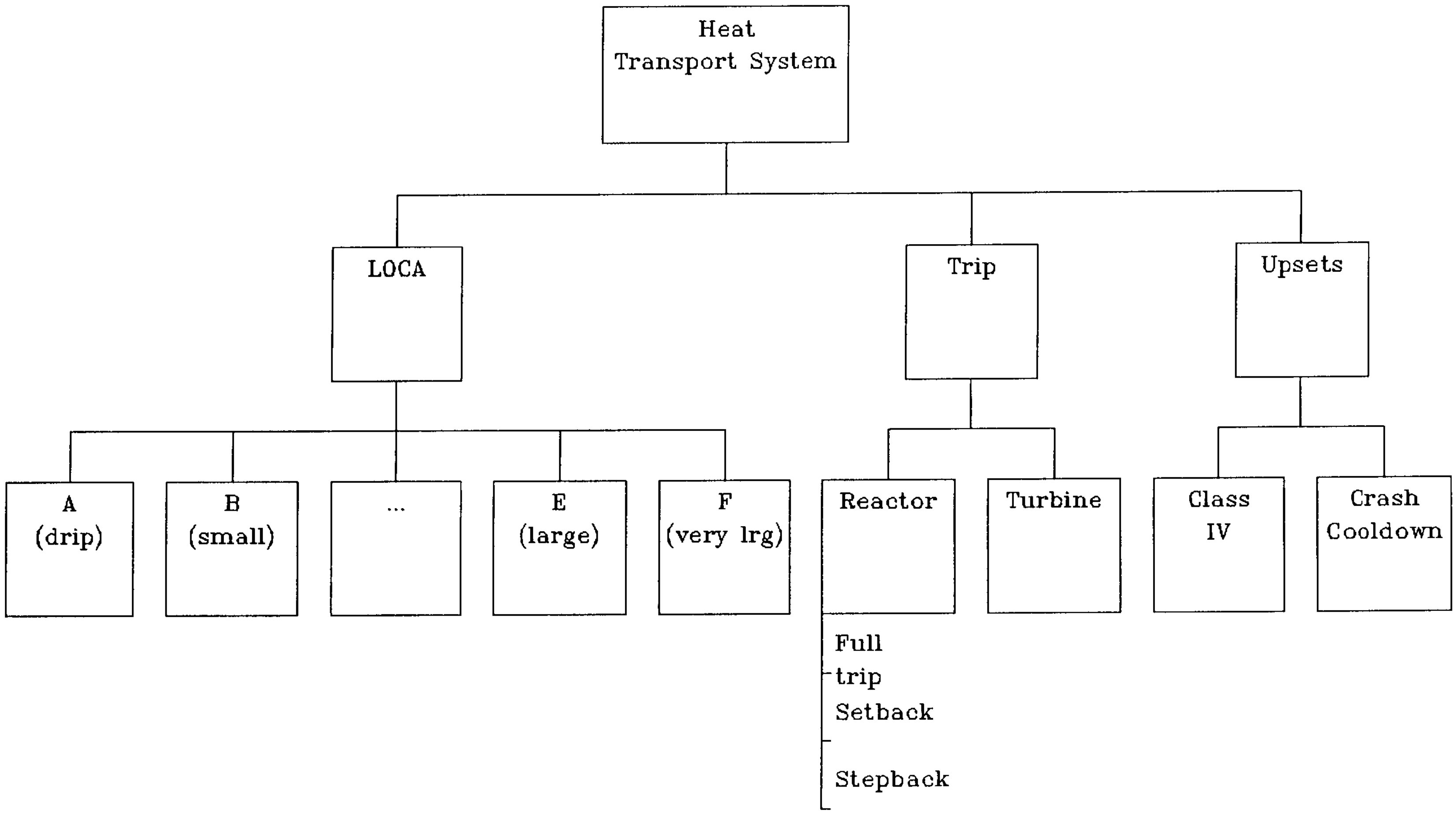
then discriminate within classes

- This is CLUSTERING

(see figure of problem tree)

Problem Tree

Reactor Operator Companion



Scoring tactics

- Could use a 'weak link' algorithm to score each object (problem within a cluster) based on a selection of relevant process signals:

- Example:

the normal surge tank level is X

the level if there were a medium size LOCA would be < X and dropping at a rate Y

the score could be constructed as follows:

100 * (X - level) / range * rate / Y * ...

thus if the level was nominal OR the rate was steady then the score = 0, indicating no LOCA of medium size.

Tactics (continued)

- Since all LOCA's are being evaluated on the same basis, the scores are relevant.

- You could not compare trips with LOCA's without introducing some degree of arbitrariness or proposing some basis of comparison. This is true for other paradigms such as if-then rules with confidence factors. (apples and oranges)

- Problem: many of the process signals have many valid nominal states.

What is normal? -> leads to the requirement for a simulator

Discussion of the role of the simulator

- Trend analyzer compared to simulator
  - -> event
  - -> expert system
  - -> blackboard
  - -> simulator (redo calcs)

- Some events do not need a simulator
  - catch: what is nominal?
  - sometimes can decide without a simulator

Summary

- **Main points of discussion:**

  problem definition -> finite vs. infinite

  inference strategy -> procedural vs. declarative

  inference tactics -> exclude + score card

Conclusions

- Architecture proposed appears feasible:

simple

modular (based on functionality)

extendable

inexpensive

convenient for prototyping

DOABLE!

Future work

- Have proved the exclude + score concept

- Have prototyped time slicing on a spreadsheet only

- Have prototyped a thermalhydraulic simulator that executes better than real time on a 386 for 20+ nodes/links

- Have the hardware on site to begin testing of the blackboard /communications

- Much of the personnel in place by Sept / 90 (student based)