NON-VON: A Parallel Machine Architecture
For Knowledge-Based Information Processing

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ABSTRACT

NON-VON is a highly parallel machine designed to support the efficient implementation of very large scale knowledge-based systems. The utility of such a machine has been demonstrated analytically [1, 2] and through implementation of a working knowledge-based information retrieval system in which the NON-VON machine instructions were emulated in software [3]. In cooperation with the Stanford Computer Science Department, we have recently begun to implement the most important components of the machine as custom VLSI circuits.

I INTRODUCTION

The central focus of our recent research has been the investigation of highly parallel non-von Neumann machine architectures adapted to the kinds of operations that appear central to the operation of a broad class of large-scale knowledge-based systems. Our approach is based on an architecture [1] that supports the highly efficient evaluation of the most "difficult" set theoretic and relational algebraic operators. This research spans an unusual "vertical distance"—extending from the level of Al description languages, through the arena of logical formula manipulation, and down to the domain of hardware parallelism. Our initial efforts, reported in a recent Stanford doctoral dissertation [3], yielded:

1. The "top-level" architectural specification of a highly parallel machine—portions of which are to be implemented using custom nMOS VLSI circuits—which we have since come to call NON-VON.

2. An analysis of the time complexity of the essential parallel hardware algorithms to be executed on the proposed machine in the course of large-scale, meaning-based data manipulation.

3. The implementation of an operational knowledge-based information retrieval system, demonstrating the use of NON-VON (emulated in software) in support of a very high level descriptive formalism based on the language KRL [4].

Our recent work at Columbia and Stanford has focused on:

1. Progressive refinement and elaboration of the NON-VON architecture, including a preliminary functional design and high-level layout for two of the most important VLSI chips.

2. The exploration of applications of the NON-VON class of architectures to practical problems in such areas as artificial intelligence, database management, and "very-high-level" programming languages.

In this short communication, we will briefly sketch our progress to date.

II A KNOWLEDGE-BASED RETRIEVAL SYSTEM

A surprisingly large share of the kinds of information processing activities with which both human and automated data processors are charged may be viewed as involving various kinds of knowledge-based matching or retrieval problems. For our dissertation research, we chose a concrete task of manageable scope that captured many of the most important characteristics of the general "conceptual matching" problem: the knowledge-based document retrieval application.

The user of a knowledge-based document retrieval system formulates a high-level pattern description which is then matched against all descriptions contained in a large target collection (the set of books in a computer science library, for example). In general, the success of a match may depend on domain-specific cattories and relationships. In the case of the computer science library, for example, the system might "know about" such entities as computers, algorithms, programmers and storage devices. Certain characteristic attributes of these entities (the storage medium attribute, for example, whose values differ for different kinds
of storage devices] might also be included in this domain-specific knowledge.

Typical of the kinds of relationships which might be
embodied in the knowledge base of such a system is the fact
that a tape drive is a particular kind of storage device whose
storage medium is always magnetic tape. A simple deductive
inference based on this relationship might establish
that a pattern description in which the subject is described
as a storage device with magnetic tape as its medium would
be satisfied by a target description with subject described
as a tape drive. The description language used in our ex-
perimental system is based closely on KRL, the document
description shown below may suggest some of its most im-
portant features:

a Document
  authors
  set-with-all-of
    Thompson
    Walters
  set-of
    an Engineer
    countries-of-publication
      set-with-any-of
        USA
        Great-Britain
  subject
    involves
      an invention with
        purpose
        or
          Power-generation
          Power-transmission
    printing-dates
      set-with-exactly
        1959
        1962
  a Textbook


III PREDICATE LOGIC FOR SPECIFICATION AND EXECUTION

The rules defining the semantics of matching within
our knowledge-based description language were not em-
bedded intrinsically within the code of the retrieval system,
but were instead formulated as an independent, separable
set of twenty-two axioms expressed in a restricted first-
order predicate calculus. One of these axioms (which em-
body the basis on which a target description of the form
"a Storage-device with medium = Magnetic-tape" would
successfully match a less restrictive description of the form
"a Storage-device" is presented below:

\[
\text{Per-imp-Per (tar-per, pat-per) } \equiv \\
\exists \text{ proto} \\
(\text{Per/proto (pat-per, proto)} \land \\
\forall \text{ slot} \\
(\exists \text{ pat-fill} . \\
\text{Obj-slot-fill (pat-per, slot, pat-fill)}) \\
\lor \exists \text{ pat-fill, tar-fill} \\
(\text{Obj-slot-fill (pat-per, slot, pat-fill)} \land \\
\text{Obj-slot-fill (tar-per, slot, tar-fill)} \land \\
\text{Duplication (tar-fill, pat-fill))}
\]

The set of matching axioms serves not only as a modu-
lar, perspicuous and easily formulated specification of the
semantics of the knowledge-based description language, but
as an executable "program" for actually carrying out the
matching process which it describes. More precisely, the
matching process is carried out by a procedure called LSEC
(for Logical Satisfaction by Extensional Constraint), which
interprets the set of axioms to identify all target descrip-
tions that match the user-specified pattern description ac-
cording to the matching rules for the description language,
making reference to the domain-specific knowledge base.
(Details of the LSEC algorithm are presented in [3].)

IV NON-VON AS A LOGIC ENGINE

Unfortunately, the LSEC algorithm relies very heavily
on the execution of several operations which, on a von
Neumann machine, are quite expensive when their operands
comprise a large amount of data (as is the case in the sort of
application with which we are concerned). Specifically, the
algorithm repeatedly evaluates the most expensive operators
of a relational algebra [5]—in particular, the equijoin opera-
tion. NON-VON evaluates the most time-consuming rela-
tional algebra operators in a highly efficient manner, par-
ticularly when the argument relations are large. The ar-
chitecture in fact achieves an asymptotic improvement of
\(O(\log n)\), with very favorable constant factors, over the best
evaluation methods known for these operators on a conven-
tional system, without the use of redundant storage, and
using currently available and potentially competitive tech-
ology.

V THE NON-VON ARCHITECTURE

At the top level, the NON-VON machine architec-
ture comprises a Secondary Processing Subsystem (SPS),
based on a bank of "intelligent" rotating storage devices
and designed to provide very high accessing and processing
bandwidth, along with a smaller, but faster Primary
Processing Subsystem (PPS), again utilizing a high degree
of parallelism, in which the relational algebraic operators may be very quickly evaluated. Transfer between the two devices is based on a process of hash partitioning, which is performed entirely in hardware by logic associated with the individual disk heads, and which divides the argument relations into key-disjoint buckets suitable for “internal” evaluation.

In our demonstration system, the operation of NON-VON was emulated sequentially (in MAC/SP on the DEC KL-10 at the Stanford Artificial Intelligence Laboratory), and hence, so inefficiently that testing using a large sample document collection would have been impractical. On a physical implementation of NON-VON, though, our knowledge-based retrieval system would in a sense be able to look at all documents in the library “at once”, applying a considerable amount of physical hardware concurrency to a much more complex (inferential) matching task than has previously been attacked using parallel hardware.

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