PARALLEL SORTING - A BIBLIOGRAPHY

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The field of parallel sorting has grown enormously in the past decade. There are many incomparable models of parallel computation being used. Some results span many models but as a rule the various branches seem destined to diverge. However we felt it was useful and instructive to collect together the different investigations into one bibliography. We have included other problems that are inextricably linked to sorting: searching, merging, and computing order statistics such as the median and the maximum. We have tried to classify each paper.

We have avoided the classifications SIMD and MIMD in favor of the perhaps equally confusing classifications of *shared memory model* and *interconnected networks*. The latter refers to models where the routing of data and messages has been restricted, usually by a network of a familiar topology. We further distinguish the *distributed computation model* in which communication in the interconnection network is asynchronous. The few papers on *vector machines* have been noted.

We have pigeon–holed many papers as discussing *sorting machines*, i.e. special purpose hardware. These designs as a rule do not display any theoretical advancement. In particular, they usually sort N items in $O(N)$ time using $O(N)$ hardware. This can be done in several simple ways that have been repeatedly rediscovered. Related to sorting machines, but often more ingenious, are the *bubble-memory* designs. Also related are the *VLSI* designs, however they are more closely allied to interconnection networks. Many of the assumptions used in the theoretical analysis of VLSI designs have recently been questioned which has raised many open problems.

The theoretical basis of much of the work on comparison-based sorting can be traced to either the study of *sorting networks* or *parallel decision trees*. Sorting networks, ostensibly unrelated to interconnection networks, are "hard–wired" arrays of comparators. The premier result in parallel sorting is the existence of an $O(\log N)$ time sorting network as shown by Ajtai, et al. In the parallel decision tree model there is no penalty for scheduling and allocating work to the processing elements and there is no cost for routing data. The *width* of a computation is the maximum number of simultaneous comparisons and the *depth* is the number of parallel comparison steps in the worst case. Usually the question asked is for a given width what is the minimum depth? The problem of sorting in *rounds* asks for a given depth what is the minimum width?

External sorting refers to the study of designs where the amount of data dwarfs the number of processors. These are based on standard merging approaches as well the substitution of normal comparison steps with "merge-and-split" operations. Papers on *merging*, however, are new parallel algorithms. *Order statistics* papers are usually concerned with only one problem, while *dictionary machines* support order statistics, insertion, deletion, and searchs. Discrete *parallel searching* is presumably related to uncited work in root-finding for monotonic functions and max-finding for unimodal functions in parallel. Those papers that we have not seen or cannot classify are simply designated *miscellaneous*.

The citations are appended by one of these designations which are sometimes followed by an additional comment.

AM	Associative memory design
BM	Bubble-memory design
DC	Distributed computation model
DM	Dictionary machine
ES	External sorting
IN	Interconnection network model
M	Merging
MISC	Miscellaneous topics
OS	Order statistics
PDT	Parallel decision trees
PR	Permutation routing
PS	Parallel searching
SM	Sorting machine
SMM	Shared memory model
SN	Sorting network
SURVEY	Survey paper
VLSI	VLSI designs
VM	Vector machine

In a bibliography like this the most difficult decision is what not to include. Many related topics have been, perhaps arbitrarily, omitted. These include some theoretical topics such as parallel prefix computation and sorting with networks of stacks and queues. We at one time included the topic of concurrent management of binary search trees but then deleted those papers. The important and copious literature on routing permutations in networks is only briefly touched. The topic of associative memories, i.e. parallel searching of unordered data, is only included in the context of sorting. The related field of database machines is not really mentioned.

This bibliography represents a first stage of an annotated bibliography on parallel sorting, we are very interested in any results not cited here. We are interested in the applications of parallel sorting in addition to the algorithms themselves. We would like to compile a list of real projects that have used parallel sorting.

Many of the papers appeared as technical reports and conference proceedings as well; we usually assume that no information is contained in only the earlier versions. Some repetitions in the bibliography occur if one reference might be inaccessible or when the overlap was uncertain. Some classifications are incomplete or even wrong and we would appreciate any advice.

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