

Digital processing device

The invention concerns a digital processing device P, particularly for processing of digital data and signal structures, wherein the data and signal structures comprise repeated sequences and/or nested patterns, and wherein
5 the processing device P generally is configured as a regular tree with $n+1$ levels $S_0, S_1, \dots, S_n$ and of degree k .

Processing of large data volumes with use of repeated or recursive operations on very large data volumes can even in a restricted number often be a bottleneck when using conventional microprocessors and is thus amenable to
10 massively parallel solutions wherein a very large number of processing elements simultaneously execute different operations in parallel on a large data stream, but possibly also parallel operations on several data streams. If such large data volumes appear in a form of data or signal structures with repeated sequences and/or nested patterns, the processing can be made more
15 effective by being realized in parallel on the same or several different levels

From US Patent No. 486020 (Stolfo & al.) there is known a parallel processing device structured as a binary tree, wherein a very large number of processors, each with their own I/O unit are used. Generally Stolfo & al. discloses a computer with a very large number of processors connected in a
20 binary tree structure such that each processor apart from those which constitute the root and the leaves of the tree has a single parent processor and two child processors. The processors typically work synchronously with data which are transmitted thereto from the parent processor and communicate the results on to the nearest succeeding processors, that is the parent processors' children. Simultaneously the child processors and the parent processor may
25 also communicate with each other. According to Stolfo & al. each node constitutes a processing element which comprises a processor in the proper sense, a read/write memory or a random access memory, and an I/O device. The I/O device provides interfaces between each processing element and its
30 parent and child processing elements such that a substantial improvement in speed whereby data are sent through the binary tree structure is obtained. As the binary tree structure has a processing element in every single node, the processing device will generally comprise $2^n - 1$ processing elements, that is 1023 processing elements if the binary tree is realized with 10 levels. In a
35 preferred embodiment the known parallel processing device has a clock

frequency of 12 MHz, which in the case of using a tree with 1023 processors which each has an average instruction cycle time of 1.8 μ s, provides a processing performance of about 570 million instructions per second.

5 A binary parallel processor of this kind may for instance be well suited for handling decomposable or partitionable data processing problems, for instance searching in large information volumes. A partitionable search problem can be defined as a problem where a query about a relation between an object x and an object set corresponds to a repeated use of a commutative and associative binary operator b which has an identity, and a primitive query 10 which is applied between a new object x and each element f in the set F. One then has a partitionable search problem when the logic function OR is combined with the primitive query "is $x = f$ " applied between the object x and each element $f \in F$. As mentioned by Stolfo & al., a problem which consists of answering a query about set F, may be answered by combining the 15 answers of the queries applied to arbitrary subsets of F. The problem is in other words partitionable or decomposable and well suited for rapid execution by means of parallel processing. The set F is partitioned in a number of arbitrary subsets equal to the number of available processors. The primitive query q is then applied in parallel in each processor between the 20 unknown x which is communicated to all processors and the locally stored element f in the set F. The results are then combined in parallel by $\log_2 N$ repetitions of the operator b, as a number of computations first is executed on $N/2$ adjacent pairs of processors and then a corresponding number of computations on $N/4$ pairs of processors with the results from the first 25 computations. The operations hence move during the process to overlying levels in the binary tree, in other words from child processors to the parent processor etc. and are repeated in parallel on each level.

There is however a number of data processing problems wherein the data and signal structures comprise repeated sequences and/or nested patterns which 30 are such that a processing device of the kind that is disclosed in US Patent No. 4860201 does not provide the desired flexibility or may not at all be suited for handling the problem. A binary tree structure as disclosed therein presupposes in principle that the problem can be binary partitioned and that operations take places in parallel on the same level. However, there may be 35 problems which demand another degree of decomposition and where processing must be able to take place in parallel, but on different levels in the

tree structure. The problems can also be partitioned such that it will be desirable with a larger partitioning capacity on one and the same level in some of the subtrees in the tree structure, and this in practice requires solutions which takes its starting point in a general tree structure which not
 5 only has an arbitrary number of levels, but also arbitrary degree, while nodes in subtrees not are only connected with the parent node of the tree in question, but for instance may be connected to a node on the same or underlying levels in neighbour trees. An increased degree of connectivity in a tree structure with a desired number of levels and of arbitrary degree will
 10 hence make it possible to reconfigure the original tree structure, either in the form of reduced trees or simple or complex graphs. Simultaneously can one or more of the leaf nodes be combined and take over the function of the parent node in question.

The object to the present invention is thus to provide a processing device
 15 which particularly suited for processing large data volumes in massive parallelism and on different levels in a general tree structure, but which simultaneously also can be configured arbitrarily as nested circuits on different levels and preferably under determined conditions such that a selected configuration on the given level is generated recursively by a
 20 configuration on an underlying level. Particularly it is the object that the processing device according to the invention shall be able to realize an MIMD processing device, that is a processing device which works with multiple instructions and multiple data.

The above-mentioned and other objects are obtained according to the
 25 invention with a digital processing device which is characterized in that the processing device P is provided in the form of a circuit P_n on the level S_n and forms the root node of the tree, that the nearest level S_{n-1} is provided nested in the circuit P_n and comprises k circuits P_{n-1} which form the child nodes of the root node, that generally an underlying level S_{n-q} in the circuit P_n , where q
 30 $\in \{1, 2, \dots, n-1\}$, comprises k^q circuits P_{n-q} provided nested in the k^{q-1} circuits P_{n-q+1} on the overlying level S_{n-q+1} , each circuit P_{n-q+1} on this level comprising k circuits P_{n-q} , that a defined zeroth level $S_{n-q} = S_0$ in the circuit P_n for $q = n$ comprises from $k^{n-1} + 1$ to k^n circuits P_0 which constitute kernel processors in the processing device P and on this level S_0 form leaf nodes in the tree, the
 35 kernel processor P_0 being provided nested in a number of 1 to k in each of the k^{n-1} circuits P_1 on the level S_1 , that each of the circuits $P_1, P_2 \dots P_n$ on

respective levels $S_1, S_2 \dots S_n$ comprises a logic unit E which generally is connected with those circuits $P_0, P_1 \dots P_{n-1}$ on the respective nearest underlying level $S_0, S_1 \dots S_{n-1}$ provided nested in the respective circuits $P_1, P_2, \dots P_n$ and according to choice configures a network of the former circuits in the respective circuits $P_1, P_2 \dots P_n$, and that each of the circuits $P_0, P_1 \dots P_n$ has identical interfaces I .

Advantageously a first embodiment of the processing device according to the invention is characterized in that the zeroth level S_0 comprises k^n kernel processors P_0 , that a kernel processor P_0 recursively maps a circuit P_1 on the overlying level with a factor $r = k$, such that the tree is a unreduced or complete tree, and that generally a circuit P_{n-q} on the level S_{n-q} maps a circuit P_{n-q+1} on the overlying level S_{n-q+1} recursively with the factor $r = k$.

Further a second embodiment of the processing device according to the invention is advantageously characterized in that the zeroth level S_0 comprises rk^{n-1} kernel processors $P_0, 1 < r < k$, that a kernel processor P_0 maps a circuit P_1 on the overlying level S_1 with the same factor r , such that the tree is a symmetrically reduced or balanced tree, and that generally a circuit P_{n-q} on all levels from the level S_1 maps a circuit P_{n-q+1} on the overlying level S_{n-q+1} recursively with the factor $r = k$.

Finally a second embodiment of the processing device according to the invention is advantageously characterized in that respectively from 1 to k kernel processors are provided nested in each circuit P_1 on the level S_1 , that at least one of the circuits P_1 comprises at least 2 and at most $k-1$ kernel processors P_0 , such that the total number of kernel processors P_0 on the level S_0 is at least $k^{n-1} + 1$ and at the most $k^n - 1$ and the tree becomes an asymmetrically reduced or unbalanced tree, and that generally a circuit P_{n-q} on the level S_{n-q} is mapped by the circuits P_{n-q-1} nested in the respective circuit P_{n-q} .

According to the invention the kernel processor P_0 advantageously comprises at least one combinatorial unit C and a memory unit M connected with at least one combinatorial unit C , at least a part of the memory unit M preferably being configured as a register unit R . In the latter case can preferably then at least one combinatorial unit C and the register unit R be configured as an arithmetic logic unit ALU . Advantageously comprises according to the invention the logic unit at least one combinatorial unit C and

a register unit R connected with the at least one combinatorial unit, the at least one combinatorial unit C preferably being a multiplexer. It is then advantageous that the logic unit E in a circuit P_{n-q} is adapted to be connected with the logic unit E in a corresponding circuit P_{n-q} on the same level as S_{n-q} in a neighbour tree.

It is also advantageous that the logic unit E in a circuit P_{n-q} is adapted to be connected with the logic unit E in circuits P_{n-q-1} , P_{n-q-2} , ... P_1 on respective underlying levels S_{n-q-1} , S_{n-q-2} , ... S_1 in a neighbour tree.

Finally it is also advantageous that the logic unit E in a circuit P_{n-q} is adapted to be connected with one or more kernel processors P_0 in a neighbour tree, either directly or via the logic unit E in the circuit P_1 , where the kernel processor P_0 or the kernel processors P_0 in question are nested.

The invention shall now be explained in more detail in connection with exemplary embodiments and with reference to the accompanying drawing, wherein

fig. 1 shows a first embodiment of the processing device according to the invention,

fig. 2 the embodiment in fig. 1 configured as a regular tree structure,

fig. 3 a second embodiment of the processing device according to the invention configured as a tree structure,

fig. 4a a third embodiment of the processing device according to the invention configured as an asymmetrically reduced tree,

fig. 4b an example of a subtree with leaf nodes in the tree structure which represents the processing device according to the invention,

fig. 4c another example of a subtree with leaf nodes in the tree structure which represents the processing device according to the invention,

fig. 5 schematically the principle for generating the processing device according to the invention as a nested circuit by recursive mapping,

fig. 6 an embodiment of the processing device according to the invention as a recursive circuit with three levels and degree four,

fig. 7 another embodiment of the processing device according to the invention as a recursive circuit with four levels and similarly degree four,

fig. 8 possible connections between the nodes in a tree corresponding to the circuit in fig. 6,

5 fig. 9 possible connections between the nodes in a tree corresponding to the circuit in fig. 7,

fig. 10 the circuit in fig. 6 or fig. 8 connected as a one-dimensional graph,

fig. 11a schematically an embodiment of a kernel processor in the processing device according to the invention,

10 fig. 11b schematically an embodiment of a circuit with a logic unit and a kernel processor in the form of a comparator unit for use in a search processor device based the processing device according to the invention,

fig. 12a the comparator unit in fig. 11b,

15 fig. 12b the connection of comparators similar to the one in fig. 12a in order to compare a pattern of for instance 3 characters, and

fig. 12c a balanced binary tree realized with circuits corresponding to the one in fig. 11b,

Fig. 1 shows symmetrically the layout of a parallel processing device according to the present invention. Formally the scheme in fig. 1 can be
20 described as follows: Given a circuit P_0 with an interface I_{P_0} and a further circuit E, there can be created a repeated sequence of circuits P_1, P_2, P_3 , with respective interfaces $I_{P_1}, I_{P_2}, \dots, I_{P_n}$, each comprising respectively k circuits $P_0, P_2, \dots, P_{n-1}$ and a single further circuit E, the interfaces I being identical for all circuits $P_0, P_1, \dots, P_n$, in other words $I_{P_0} = I_{P_1} = I_{P_2} \dots = I_{P_n}$. In each case the
25 circuit P_1 is configured as a tree network with $n+1$ levels S and of degree k . Specifically fig. 1 shows a digital processing device in the form of the circuit P_4 which forms a tree with five levels S and of degree 3. This implies as shown in fig. 1 that the circuit P_4 which is located on the level S_4 , on the underlying level comprises three circuits P_3 . Each of the circuits P_3 on the
30 level S_3 is generated with circuits P_2 on the underlying level S_2 , and each of the circuits P_2 the level S_2 is generated with three circuits P_1 on the underlying level S_1 . Finally, each of the circuits P_1 on the level S_1 is

generated with three circuits P_0 on the level S_0 . The circuits P_0 form the proper processing units in the processing device P_4 and constitute the kernel processors of P_4 . As the circuit P_4 as shown in fig. 2 is structured as a ternary tree, this implies that the level S_0 comprises a total of $3^4 = 81$ kernel processors P_0 , the overlying level S_1 27 circuits P_1 and the following level S_2 9 circuits P_2 . Finally the level S_3 has 3 circuits P_3 . Each of the circuits P_0 , P_1 , P_2 , P_3 constitutes the nodes in the tree in fig. 2. The kernel processors P_0 constitute the leaf nodes of the tree and the circuit P_4 the root node of the tree. Structured in this way the tree in fig. 2 appears as a recursive ternary tree, as a circuit on an arbitrary level S maps the circuit on the nearest following overlying level recursively with a mapping factor k which in this case is 3. Each of the circuits P_1 , P_2 , P_3 , P_4 , additionally comprises a logic unit E , such that the logic units E in all circuits P_1 , P_2 , P_3 , P_n physically regarded constitute the nodes of the tree. By means of the logic unit E can each node of the tree generally be connected with its parent node or its child nodes. Through the logic unit E can also each of the child nodes of the node be mutually connected. Each of the kernel processors which constitutes the leaf nodes of the tree also has respective circuits P_1 as parent nodes and can via these be connected mutually. As per se known is the problem which the processing device according to invention shall process, partitioned and the processing executed on the level S_0 in parallel by the kernel processors P_0 . The results from the kernel processors P_0 are combined and communicated further by the respective parent node P_1 . This process is repeated until the final result is present on the circuit P_4 .

Both the kernel processor P_0 and the logic unit E shall be discussed a somewhat greater detail in the following.

However, the circuit P_4 does not need to be realized as a complete or regular recursive tree. It may well be generated as a symmetrically reduced tree and this implies that the number of leaf nodes or number of kernel processors P_0 connected with the nodes P_1 , is reduced such that each circuit P_1 comprises 2 or more leaf nodes or kernel processors P_0 , but in each case less than k kernel processors P_0 . As the circuits in fig. 1 has $k = 3$, this implies that the symmetrically reduced tree as shown in fig. 3, comprises two kernel processors P_0 for each circuit P_1 . The symmetrically reduced tree on fig. 3 is in other words not regularly recursive, the recursion first from level S_1 taking place with a mapping factor 3. Generated as in fig. 1, each circuit P_1 in the

tree in fig. 3 will in addition to the logic unit E comprise only two kernel processors P_0 . The recursive mapping of circuits on an underlying level to an overlying level implies evidently that these circuits will be nested in a circuit in the overlying level and the whole circuit P_4 appears as a nested circuit.

- 5 If the circuit is an asymmetrically reduced circuit, it may appear as shown in fig. 4a. Here some of the nodes P_1 regularly have three leaf nodes P_0 , other nodes P_1 only two leaf nodes P_0 and yet other nodes P_1 only a single leaf node P_0 . In the latter case the mapping of the parent node becomes an identity mapping thereof, and for the sake of that the logic element then can be left
10 out in the circuits P_1 . If all circuits P_1 comprise only a single kernel processor P_0 , the tree which generates the circuit P_4 will appear as completely reduced, as $P_1 = P_0$ and the circuit P_4 is transformed into a regular recursive circuit P_3 with four levels and 27 kernel processors P_0 on the level S_0 . Is thus the number of levels $n+1$, a circuit P_n must have at least $k^{n-1} + 1$ kernel processors
15 on the level S_0 in order not to appear as a completely reduced tree.

- A subtree in a maximally asymmetrical reduced tree is shown in fig. 4b, this subtree comprising a node P_2 with child nodes P_1 , such that only one of nodes P_1 has two kernel processors or leaf nodes P_0 , while all of the remaining nodes P_1 in the tree only has a single leaf node P_0 , such that P_1 in these cases
20 is reduced to P_0 . With five levels or responding to the circuit in fig. 1, a circuit P_4 configured as in fig. 4b, that is with two leaf nodes in a circuit P_1 and otherwise only one leaf node in each of the remaining nodes P_1 , would appear as a maximally asymmetrical reduced tree and the number of nodes on the level S_0 in other words becomes $3^3 + 1 = 28$. Correspondingly a subtree for
25 the node P_2 in a minimally asymmetrical reduced tree is shown in fig. 4c. Here a single node P_1 comprises two leaf nodes or kernel processors P_0 , while all the remaining nodes P_1 in the tree as before comprise three leaf nodes P_0 . This of course implies that a minimally asymmetrical reduced tree corresponding to the circuit on fig. 1 in this case shall comprise a total of 80
30 kernel processors P_0 . A circuit which is generated as the tree shown in fig. 4, will of course still appear as nested on all underlying levels S_1, S_2, S_3 , but the mapping will no longer be recursive, as a circuit P_1, P_2, P_3, P_4 , will be mapped by all circuits which are located on the respective underlying level S_0, S_1, S_2, S_3 . The advantages of generating the circuit P_4 as a symmetrically
35 or asymmetrically reduced tree shall be discussed in more detail in the following.

Fig. 5 shows how a recursive self-mapping processing device P_n according to the invention is generated. The circuit P_n is realized as a tree with $n+1$ levels and of degree $k = 4$. Each of the circuits $P_0, P_1, \dots, P_{n-1}$ is nested in the respective circuits $P_1, P_2, \dots, P_n$ on the nearest overlying level $S_1, S_2, \dots, S_n$.

- 5 The number of nested levels is then of course n and the circuit P_n shall on the zeroth level S_0 defined by the kernel processors P_0 comprise a total of k^n kernel processors of this kind. Generally shall the number of circuits P_{n-q} on a level S_{n-q} , where $q = 0, 1, 2, \dots, n$, be equal to k^q .

- 10 Fig. 6 shows a nested circuit P_2 generated as a recursive tree according to the principle in fig. 5. The circuit P_2 comprises the logic unit E and nested on the underlying level S_1 four circuits P_1 which each in turn comprises the logic unit E and nested on the underlying level four circuits or kernel processors P_0 . The logic units configure the circuit P_2 as a quaternary tree with three levels S_0, S_1, S_2 , and a total of sixteen kernel processors P_0 or leaf nodes on the level S_0 . Correspondingly fig. 7 shows a sequentially generated circuit
- 15 with five levels S and $k = 4$. The circuit in fig. 7 comprises in other words a quaternary configured tree with a total of 64 kernel processors P_0 on the level S_0 . As before the interfaces I of each circuit P_0, P_1, P_2, P_3, P_4 are of course identical.

- 20 Fig. 8 shows the circuit P_2 in fig. 6 generally configured as a quaternary tree, but furthermore such that for instance the circuits P_1 , that are the nodes on the level S_1 , are mutually connected with a kernel processor P_0 in the neighbour tree on the level S_0 . Generally will the logic unit E in one of the nodes $P_1, P_2, \dots, P_n$ not only allow a connection upwards and downwards in the subtree wherein the node is located, but also a connection to nodes in
- 25 neighbour trees within one and the same level or a connection to the nearest-lying node on an underlying level in a neighbour tree. For the circuit in fig. 6 the node P_1 in a subtree hence can be connected to the first leaf node P_0 in the neighbour tree etc.

- 30 Correspondingly fig. 9 shows connections in the circuit in fig. 7, which forms a quaternary tree with four levels and a total of 64 kernel processors. Here again a node on a given level can be connected to the node in the neighbour tree on the same level and to the nearest adjacent nodes in the neighbour tree on an arbitrary underlying level.

This implies that the general tree structure can be configured via the logic element into more or less complex graphs. An example is shown in fig. 10, where the circuit P_2 in fig. 6 or fig. 8 is configured such that P_2 in reality forms a one-dimensional graph where the sixteen kernel processors P_0 are connected sequentially.

Usually the processing device according to the invention will be realized as a dedicated processing device for a determined task, for instance image processing. With basis in the general tree structure the configuring may take place task-specifically, either operatively or physically. If the configuring takes place operatively, the circuit is via the interface supplied with configuring parameters which realize the appropriate network for the processing. The configuring may then very well imply that the circuit is configured with fewer kernel processors than those which actually are provided in the circuit. The processing device according to the invention may then appear as a symmetrically reduced tree, such this is shown in fig. 3, or an asymmetrically reduced tree, such this is shown in fig. 4. For some concrete data processing tasks it can namely be required a greater number of kernel processors in one or more subtrees in order to increase the capacity of the processing device for a specific task.

As mentioned, the processing device according to the invention can also appear as a physically reduced tree, whether it is symmetrically or asymmetrically reduced. This implies that the physical circuit solution actually is realized with a smaller number of kernel processors that which is given by the number of levels S in the tree and the degree k . This may be appropriate for providing a circuit technology solution which optimally exploit the real estate conditions on the chip. If the number of kernel processors in a dedicated processing device according to the invention is reduced physically, this implies for instance a reduction in the physical size of the chip or a better exploitation of the real estate of the chip, dependent on the actual architectural solution which is selected. The condition is of course that under every circumstance the task which is assigned to the processing device, is executed.

The circuit P_0 defines a zeroth unnested level in the processing device P and constitutes a kernel processor in P .

The kernel processor P_0 is generally shown in fig. 11a and comprises a combinatorial unit C connected with a memory unit M . The interface I_{P_0} in the kernel processor P_0 which is of course is identical with the interface I of the remaining circuits $P_1, \dots, P_n$ is on the side of P_0 schematically indicated with arrows denoted "In" and "Out" for respectively the input side and the output side. The combinatorial unit C receives on the input side data in form of operative parameters which comprise the data which shall be processed. In addition the input side also supplies data in the form of configuring parameters for the kernel processor P_0 . These configuring parameters may consist of instructions as well as setting parameters for subelements in the combinatorial unit C and the memory unit M . If the data which shall be processed are in the form of structures with repeated sequences and/or nested patterns and the processing of the data is specifically directed towards determined sequences and patterns with use of a comparatively limited set of instructions, the memory unit may advantageously wholly or partly be configured as a register unit R , as each register unit may comprise a plurality of registers with respectively fixed length and address, dependent on the operations which shall be executed in the processing. The output side of the interface delivers the results of the processing, for instance to a not shown external in/out interface for the whole processing device P_n or delivers the results to other kernel processing units P_0 in the circuits P_1 or to the input interfaces in circuit $P_2, P_3, \dots, P_n$ on the overlying levels $S_2, S_3, \dots, S_n$.

A specific embodiment of the circuit P_1 for use in a search processor device is shown somewhat schematically, but with all main components in fig. 11b. The interface is shown respectively as an input interface I_{in} and an output interface I_{out} . The input interface I_{in} is connected with a multiplexer MUX with outputs respectively to the output interface I_{out} , a comparator unit COM which corresponds to the kernel processor P_0 , a first D flip-flop and a sequence control unit SC. The comparator unit COM is used in a search operation for comparing characters or strings of characters which form given patterns. In this manner it can be determined whether a given pattern can be retrieved in a form of one or more elements in a set created of different patterns. The comparator unit COM delivers the received data on to the output interface I_{out} and the result of the comparison to a latency unit LAT which can be used for delaying a positive binary value for a given number of cycles. The latency unit LAT is hence via the D flip-flop D_1 connected with

an output on the multiplexer MUX and itself delivers the result of the comparison further to the sequence control unit SC which is adapted respectively to require that the kernel processor connected before or after the present one reports a match before the present kernel processor itself can report a match, to allow a comparison of patterns in case certain parts of the pattern are missing and additionally a comparison of patterns where certain parts of the pattern may be repeated. The sequence control unit SC is on the input side connected with the D flip-flop D_1 and on the output side with the D flip-flop D_2 , the number of flip-flops being identical to the number of characters which are compared with the comparator unit COM. The sequence control unit SC must be able to receive results from a comparison operation in preceeding or succeeding processor units and is hence connected with the input interface I_{in} and the multiplexer MUX and itself reports the results of the comparison operation further via output interface I_{out} . Finally the circuit P_1 in this embodiment also comprises a result selector RS which is used for combining two result values from other kernel processors or other result selectors. The result selector RS is thus connected with respectively the input interface I_{in} and the output interface I_{out} and can perform Boolean operations on two result values or compare operations of the type greater than, less than, or equal to over a set of processors.

In a specific embodiment a digital processing device P can be adapted to different types of numeric computation in massive parallelism and the combinatorial unit C and a register unit R will then be configured as arithmetic logic unit ALU. Each kernel processor P_0 can additionally comprise a memory unit M configured as RAM and hence implement an intelligent RAM (IRAM) such that latency problems are reduced or eliminated in a data processing of this kind.

On each nested level $S_1, S_2, \dots, S_n$ there is additionally provided a further circuit in the form of a logic unit E which in itself may be a processor unit consisting of a combinatorial unit C and a register unit R. The logic unit E is generally identical for all circuits $P_1, P_2, \dots, P_n$. For example, in the circuit P the logic unit E corresponds to all components in fig. 11b with the exception of the interface I and the comparator (kernel processor) COM. In a regular binary tree the circuit P_1 in fig. 11b will of course have two kernel processors, that is two connected comparator units COM. Advantageously the circuit E on each level $S_1, S_2, \dots, S_n$ then functions as a processing unit with

the purpose of configuring the network on the respective level and possibly underlying levels where the circuit E is located in each node in the network. By supplying the circuit E with suitable network-configuring parameters, a network on a given level can be configured optimally for the processing task which shall be executed. The logic unit E is adapted to be connected with nodes on the same or underlying levels in neighbour trees and can with basis in a regular tree structure transform this into more or less complex graphs and networks in order to better handle task-specific data volumes and data rates, for instance in problems which do not lend themselves to a balanced partitioning.

The combinatorial unit in the kernel processor P_0 realized as a comparator unit COM and used in a search processor device is shown in fig. 12a. A register x contains the dataword which momentarily is located in the comparator unit COM and the register a comprises the dataword which x shall be compared to. It is from fig. 12a easily seen that four comparisons can be performed, viz. $x = a$, $x \geq a$, $x \neq a$ or $x \leq a$, and the result is delivered to the output of the multiplexer MUX. With an interconnection of the comparator units as shown in fig. 12a, simple patterns in the form of character strings can be compared. The principle is shown in fig. 12b where the illustrated and interconnected units may be able to compare the string abc , that is an a directly followed by a b , directly followed by a c .

If the processing device according to the present invention shall be implemented as a search processor device, an unreduced and balanced binary tree may be used. For each inner node in the tree, that is all nodes with exception of the root node and the leaf nodes, a multiplexer is used for deciding whether two subtrees shall receive the same data elements in parallel and whether they shall receive data sequentially. This corresponds to connecting nodes on two different levels in neighbour trees, as already mentioned.

Fig. 12c shows a search processor device realized as a binary tree with 8 kernel processors, here shown as circuits 0, 1, ... 7. In this connection it shall be remarked that when the results are fetched from two circuits or two kernel processors, these will be combined with the use of logic operations. This takes place in the result selector RS. The logic unit E in each circuit comprises as shown in fig. 11b a result selector RS which also allows that

only one of the results is selected. The result selectors used in a binary tree will in other words give a single result from a group of processor units. Simultaneously the search processing device in the form of a binary tree shall also fetch the results from a comparison of characters or character strings executed before or after the comparison of the character or the character strings which for the moment are processed by the kernel processor or the comparator unit COM. By using a sequence control unit in the logic unit the tree can be configured such that a comparison operation can be performed by choosing the results either to the right or to the left for any of the elements which compare different characters or character strings. When a plurality of comparator units additionally compares the same characters or character strings, will their preceding and succeeding results be the same. These results may be found by the same multiplexer MUX which controls the data stream being used, such that a comparison result is communicated further to any of the neighbour elements which compare the same characters or character strings. This is also realized in the search processor device as shown in fig. 12c. In this connection it shall be remarked that the same multiplexer set now is used for three separate purposes, namely for distributing data, for routing memory bits through the number of flip-flops and to provide or supply the results from comparisons of proceeding or following characters or character strings. The results from different kernel processors can however be combined by using a look-up table unit which can be connected between the subtrees and the output of the search processor device. The look-up table unit will then replace the result selectors RS shown in fig. 12c.

The nested and possibly recursively generated processing device P according to the invention can be used for realizing task-specific processing devices for processing large data volumes in massive parallelism. Examples of such tasks may be searching in large data volumes structured in the form of documents, where the search takes place in simultaneous parallel in all or a large number of documents and can for instance be directed towards retrieval, identification and comparison of patterns. Further the processing device according to the invention can for instance be configured for image processing, encryption and decryption as well as processing based on a recursive procedures generally. Applied as purely numerical processor, the processing device according to the invention could be adapted for factorisation.

The kernel processors P_0 can as mentioned be based on standard microelectronic components and these may for instance be implemented as a so-called field programmed gate array (FPGA) or an application specific integrated circuit (ASIC), in both cases with a varying scale of integration.

5 As the processing device according to the invention can be scaled in several dimensions, for instance with regard to processing capacity or connectivity, the realization is however not bound to a determined technology or a determined technological level, but may in practice be implemented based on the at any time available technological level, such that the performance of the
10 processing device can be improved in step with the technological development.

In principle the processing device P according to the present invention could be realized with arbitrary degree k and an arbitrary number $n+1$ in levels S. In each case the number of kernel processors will be given by k^n . In reality
15 both k and n will be limited by the microelectronic technology which is available for realizing processing device P and particularly then the available integration scale. Dependent of both technology and the specific processing tasks which processing devices P shall be realized for, the chosen values for k and n can be made the object of a balanced judgement, for instance
20 dependent on the need for parallelism and degree of partitioning. In a practical realized implementation the processing device P_n for instance is realized with $k = 8$ and $n = 3$, that is 512 kernel processors P_0 on the level S_0 .

By using standard microelectronics based on a conventional inorganic semiconductor technology, for instance silicon technology, the connectivity, that is the interconnection of the circuits in a network may offer problems in the form of complexity and long signal paths if the processing device P is
25 realized integrated in a substantial planar technology on a substrate. In principle the network however is reconfigurable, that is that a network configured for one task may be configured in to another network, for instance
30 with the use of suitable configuring parameters via the logic unit E. For certain tasks within massive parallel processing it may however be desirable with a higher degree of connectivity and ideally with total connectivity, that is every node being mutually connected. In this case the degree of connectivity for m nodes scales as $m^2/2$ and shall even for a limited number
35 m, for instance 512 be difficult to realize with use of conventional circuit topologies. A possibility for realizing a circuit topology is to stack circuits

5 based on organic thin-film technology above each other in a volumetric configuration and using both vertical and horizontal conducting structures for generating connections between the separate nodes or circuits, such that a three-dimensional network topology is obtained which will allow a very high degree of connectivity. Such technologies are disclosed in NO patent application 19982518 (Gudesen, Leistad & Nordal) which is directed towards an integrated scalable data processing device with MIMD architecture and realized as a volumetrically structured unit, i.a. with optimal network topologies and high degree of connectivity for massive parallel processing.



PATENT CLAIMS

1. A digital processing device P, particularly for processing of digital data and signal structures, wherein the data and signal structures comprise repeated sequences and/or nested patterns, and wherein the processing device P generally is configured as a regular tree with $n+1$ levels $S_0, S_1, \dots, S_n$ and of degree k , characterized in that the processing device P is provided in the form of a circuit P_n on the level S_n and forms the root node of the tree, that the nearest level S_{n-1} is provided nested in the circuit P_n and comprises k circuits P_{n-1} which form the child nodes of the root node, that generally an underlying level S_{n-q} in the circuit P_n , where $q \in \{1, 2, \dots, n-1\}$, comprises k^q circuits P_{n-q} provided nested in the k^{q-1} circuits P_{n-q+1} on the overlying level S_{n-q+1} , each circuit P_{n-q+1} on this level comprising k circuits P_{n-q} , that a defined zeroth level $S_{n-q} = S_0$ in the circuit P_n for $q = n$ comprises from $k^{n-1} + 1$ to k^n circuits P_0 which constitute kernel processors in the processing device P and on this level S_0 form leaf nodes in the tree, the kernel processor P_0 being provided nested in a number of 1 to k in each of the k^{n-1} circuits P_1 on the level S_1 , that each of the circuits $P_1, P_2, \dots, P_n$ on respective levels $S_1, S_2, \dots, S_n$ comprises a logic unit E which generally is connected with those circuits $P_0, P_1, \dots, P_{n-1}$ on the respective nearest underlying level $S_0, S_1, \dots, S_{n-1}$ provided nested in the respective circuits $P_1, P_2, \dots, P_n$ and according to choice configures a network of the former circuits in the respective circuits $P_1, P_2, \dots, P_n$, and that each of the circuits $P_0, P_1, \dots, P_n$ has identical interfaces I.
2. A digital processing device according to claim 1, characterized in that the zeroth level S_0 comprises k^n kernel processors P_0 , that a kernel processor P_0 recursively maps a circuit P_1 on the overlying level with a factor $r = k$, such that the tree is a unreduced or complete tree, and that generally a circuit P_{n-q} on the level S_{n-q} maps recursively a circuit P_{n-q+1} on the overlying level S_{n-q+1} with the factor $r = k$.
2. A digital processing device P according to claim 1, characterized in that the zeroth level S_0 comprises rk^{n-1} kernel processors P_0 , $1 < r < k$, that a kernel processor P_0 maps a circuit P_1 on the overlying level S_1 with the same factor r , such that the tree is a symmetrically reduced or balanced tree, and that generally a circuit P_{n-q} on all levels from the level S_1 maps a circuit P_{n-q+1} on the overlying level S_{n-q+1} recursively with the factor $r = k$.



4. A digital processing device P according to claim 1, characterized in that respectively from 1 to k kernel processors are provided nested in each circuit P_1 on the level S_1 , that at least one of the circuits P_1 comprises at least 2 and at most k-1 kernel processors P_0 , such that the total number of kernel processors P_0 on the level S_0 is at least $k^{n-1} + 1$ and at the most $k^n - 1$ and the tree becomes an asymmetrically reduced or unbalanced tree, and that generally a circuit P_{n-q} on the level S_{n-q} is mapped by the circuits P_{n-q-1} nested in the respective circuit P_{n-q} .
5. A digital processing device P according to claim 1, characterized in that the kernel processor P_0 at least comprises one combinatorial unit C and a memory unit M connected with at least one combinatorial unit C.
6. A digital processing device P according to claim 5, characterized in that at least a part of the memory unit M is configured as a register unit R.
7. A digital processing device P according to claim 6, characterized in that at least one combinatorial unit C and a register unit R are configured as an arithmetic logic unit ALU.
8. A digital processing device P according to claim 1, characterized in that the logic unit E comprises at least one combinatorial unit C and a register unit R connected with the at least one combinatorial unit C.
9. A digital processing device P according to claim 8, characterized in that at least one combinatorial unit C is a multiplexer.
10. A digital processing device P according to claim 9, characterized in that the logic unit E in a circuit P_{n-q} is adapted to be connected with the logic unit E in a corresponding circuit P_{n-q} on the same level S_{n-q} in a neighbour tree.
11. A digital processing device P according to claim 9, characterized in that the logic unit E in a circuit P_{n-q} is adapted to be connected with the logic unit E in circuits P_{n-q-1} , P_{n-q-2} , ... P_1 on respective underlying levels S_{n-q-1} , S_{n-q-2} , ... S_1 in a neighbour tree.
12. A digital processing device P according to claim 11, characterized in that the logic unit E in a circuit P_{n-q} is adapted to be connected with one or more kernel processors P_0 in a neighbour tree, either directly or via the logic

unit E in the circuit P_1 , where the kernel processor P_0 or the kernel processors P_0 in question are nested.

