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LOOK-UP TABLE WRITE

Abstract

A digital data processor includes an instruction memory storing instructions each specifying a data processing operation and at least one data operand field, an instruction decoder coupled to the instruction memory for sequentially recalling instructions from the instruction memory and determining the data processing operation and the at least one data operand, and at least one operational unit coupled to a data register file and to the instruction decoder to perform a data processing operation upon at least one operand corresponding to an instruction decoded by the instruction decoder and storing results of the data processing operation. The at least one operational unit is configured to perform a table write in response to a look up table write instruction by writing at least one data element from a source data register to a specified location in a specified number of at least one table.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of and claims priority to U.S. patent application Ser. No. 18/436,652, filed Feb. 8, 2024, which claims priority to U.S. patent application Ser. No. 17/686,584, filed Mar. 4, 2022, now U.S. Pat. No. 11,960,891, issued Apr. 16, 2024, which claims priority to U.S. patent application Ser. No. 16/570,519, filed Sep. 13, 2019, now U.S. Pat. No. 11,269,636, issued Mar. 8, 2022, which claims priority to U.S. Provisional Patent Application No. 62/853,120, filed May 27, 2019, all of which are hereby incorporated herein by reference in their entireties. [0002] The present application relates to the following commonly assigned co-pending applications titled: “Look-Up Table Read,” U.S. patent application Ser. No. 16/570,640, filed Sep. 13, 2019, Attorney Docket No. TI-77734; “Look-Up Table Initialize,” U.S. patent application Ser. No. 16/570,778, filed Sep. 13, 2019, Attorney Docket No. TI-77747; “Look-Up Table Read,” U.S. patent application Ser. No. 16/570,874, filed Sep. 13, 2019, Attorney Docket No. TI-77748; and “Histogram Operation,” U.S. patent application Ser. No. 16/570,931, filed Sep. 13, 2019, Attorney Docket No. TI-77749, all of which are incorporated herein by reference in their entireties.

BACKGROUND

[0003] Modern digital signal processors (DSP) face multiple challenges. Workloads continue to increase, requiring increasing bandwidth. Systems on a chip (SOC) continue to grow in size and complexity. Memory system latency severely impacts certain classes of algorithms. As transistors get smaller, memories and registers become less reliable. As software stacks get larger, the number of potential interactions and errors becomes larger. Even wires become an increasing challenge. Wide busses are difficult to route. Wire speeds continue to lag transistor speeds. Routing congestion is a continual challenge.

[0004] One technique useful for filtering functions is table look up. A data table is loaded into memory storing a set of results at a memory location corresponding to an input parameter. To perform a function, the input parameter is used to recall the pre-calculated result. This technique can be particularly valuable for seldom used and difficult to calculate mathematical functions.

SUMMARY

[0005] In accordance with at least one example of the disclosure, a digital data processor includes an instruction memory storing instructions each specifying a data processing operation and at least

one data operand field, an instruction decoder coupled to the instruction memory for sequentially recalling instructions from the instruction memory and determining the data processing operation and the at least one data operand, and at least one operational unit coupled to a data register file and to the instruction decoder to perform a data processing operation upon at least one operand corresponding to an instruction decoded by the instruction decoder and storing results of the data processing operation. The at least one operational unit is configured to perform a table write in response to a look up table write instruction by writing at least one data element from a source data register to a specified location in a specified number of at least one table.

[0006] In accordance with another example of the disclosure, a method includes performing, by an operational unit coupled to a data register file and to an instruction decoder, a table write in response to a look up table write instruction by writing at least one data element from a source data register to a specified location in a specified number of at least one table.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] For a detailed description of various examples, reference will now be made to the accompanying drawings in which:

[0008] FIG. 1 illustrates a dual scalar/vector datapath processor according to one embodiment;

[0009] FIG. 2 illustrates the registers and functional units in the dual scalar/vector datapath processor illustrated in FIG. 1;

[0010] FIG. 3 illustrates a global scalar register file;

[0011] FIG. 4 illustrates a local scalar register file shared by arithmetic functional units;

[0012] FIG. 5 illustrates a local scalar register file shared by multiply functional units;

[0013] FIG. 6 illustrates a local scalar register file shared by load/store units;

[0014] FIG. 7 illustrates a global vector register file;

[0015] FIG. 8 illustrates a predicate register file;

[0016] FIG. 9 illustrates a local vector register file shared by arithmetic functional units;

[0017] FIG. 10 illustrates a local vector register file shared by multiply and correlation functional units;

[0018] FIG. 11 illustrates pipeline phases of a central processing unit according to an example embodiment;

[0019] FIG. 12 illustrates sixteen instructions of a single fetch packet;

[0020] FIG. 13 illustrates an instruction coding example in accordance with one embodiment;

[0021] FIG. 14 illustrates the bit coding of a condition code extension slot 0;

[0022] FIG. 15 illustrates the bit coding of a condition code extension slot 1;

[0023] FIG. 16 illustrates the bit coding of a constant extension slot 0;

[0024] FIG. 17 is a partial block diagram illustrating constant extension;

[0025] FIG. 18 illustrates a carry control for SIMD operations according an example embodiment;

[0026] FIG. 19 illustrates the data fields of an example look up table configuration register;

[0027] FIG. 20 illustrates the data fields in an example look up table enable register which specifies the type of operations permitted for a particular table set;

[0028] FIG. 21 illustrates look up table organization for one table for that table set;

[0029] FIG. 22 illustrates look up table organization for two tables for that table set;

[0030] FIG. 23 illustrates look up table organization for four tables for that table set;

[0031] FIG. 24 illustrates look up table organization for eight tables for that table set;

[0032] FIG. 25 illustrates look up table organization for sixteen tables for that table set;

[0033] FIG. 26 illustrates an example of the operation of the look up table read instruction for four parallel tables, a data element size of byte and no promotion in accordance with an example

embodiment;

[0034] FIG. **27** illustrates an example of the operation of the look up table read instruction for four parallel tables, a data element size of byte and 2× promotion in accordance with an example embodiment;

[0035] FIG. **28** illustrates an example of the operation of the look up table read instruction for four parallel tables, a data element size of byte and 4× promotion in accordance with an example embodiment;

[0036] FIGS. **29A** and **29B** together illustrate an example embodiment of implementation of the promotion;

[0037] FIG. **30** illustrates an example of an extension element illustrated in FIG. **29A**;

[0038] FIG. **31** illustrates a multiplex control encoder controlling multiplexers illustrated in FIGS. **29A** and **29B**;

[0039] FIG. **32** illustrates an example of the operation of the look up table read instruction for four parallel tables, a data element size of word, and 2-element interpolation in accordance with an example embodiment;

[0040] FIG. **33** illustrates an example of the operation of the look up table read instruction for four parallel tables, a data element size of word, and 4-element interpolation in accordance with an example embodiment;

[0041] FIG. **34** illustrates an example of the operation of a multi-stage butterfly unit to reorder data from a look up table prior to writing the reordered data to a destination register in response to execution of a look up table read instruction in accordance with an example embodiment;

[0042] FIG. **35** illustrates an example of the operation of a look up table write instruction for four parallel tables with a data element size of word in accordance with an example embodiment;

[0043] FIGS. **36A** and **36B** illustrate examples of the operation of a look up table initialization instruction in accordance with example embodiments;

[0044] FIG. **37** illustrates an example of the operation of a histogram instruction for four parallel histograms in accordance with an example embodiment; and

[0045] FIG. **38** illustrates an example of the operation of a weighted histogram instruction for four parallel histograms in accordance with an example embodiment.

DETAILED DESCRIPTION

[0046] FIG. **1** illustrates a dual scalar/vector datapath processor **100** according to an example embodiment of this disclosure. Processor **100** includes separate level one instruction cache (L1I) **121** and level one data cache (L1D) **123**. Processor **100** includes a level two combined instruction/data cache (L2) **130** that holds both instructions and data. FIG. **1** illustrates the connection between level one instruction cache **121** and level two combined instruction/data cache **130** (bus **142**). FIG. **1** illustrates the connection between level one data cache **123** and level two combined instruction/data cache **130** (bus **145**). The level two combined instruction/data cache **130** stores both instructions to back up level one instruction cache **121** and data to back up level one data cache **123**. The level two combined instruction/data cache **130** is further connected to higher level cache and/or main memory in a manner known in the art and not illustrated in FIG. **1**. In one embodiment, central processing unit core **110**, level one instruction cache **121**, level one data cache **123** and level two combined instruction/data cache **130** are formed on a single integrated circuit. This single integrated circuit optionally includes other circuits.

[0047] Central processing unit core **110** fetches instructions from level one instruction cache **121** as controlled by instruction fetch unit **111**. Instruction fetch unit **111** determines the next instructions to be executed and recalls a fetch packet sized set of such instructions. The nature and size of fetch packets are further detailed below. As known in the art, instructions are directly fetched from level one instruction cache **121** upon a cache hit (if these instructions are stored in level one instruction cache **121**). Upon a cache miss (the specified instruction fetch packet is not stored in level one instruction cache **121**), these instructions are sought in level two combined cache **130**. In one

embodiment, the size of a cache line in level one instruction cache **121** equals the size of a fetch packet. The memory locations of these instructions are either a hit in level two combined cache **130** or a miss. A hit is serviced from level two combined cache **130**. A miss is serviced from a higher level of cache (not illustrated) or from main memory (not illustrated). As is known in the art, the requested instruction may be simultaneously supplied to both level one instruction cache **121** and central processing unit core **110** to speed use.

[0048] Central processing unit core **110** includes plural functional units (also referred to as “execution units”) to perform instruction specified data processing tasks. Instruction dispatch unit **112** determines the target functional unit of each fetched instruction. In one embodiment, central processing unit **110** operates as a very long instruction word (VLIW) processor capable of operating on plural instructions in corresponding functional units simultaneously. A compiler may organize instructions in execute packets that are executed together. Instruction dispatch unit **112** directs each instruction to its target functional unit. In one embodiment, the functional unit assigned to an instruction is completely specified by the instruction produced by a compiler in that the hardware of central processing unit core **110** has no part in this functional unit assignment. Instruction dispatch unit **112** may operate on plural instructions in parallel. The number of such parallel instructions is set by the size of the execute packet. This will be further detailed below.

[0049] One part of the dispatch task of instruction dispatch unit **112** is determining whether the instruction is to execute on a functional unit in scalar datapath side A **115** or vector datapath side B **116**. An instruction bit within each instruction called the s bit determines which datapath the instruction controls. This will be further detailed below.

[0050] Instruction decode unit **113** decodes each instruction in a current execute packet. Decoding includes identification of the functional unit performing the instruction, identification of registers used to supply data for the corresponding data processing operation from among possible register files, and identification of the register destination of the results of the corresponding data processing operation. As further explained below, instructions may include a constant field in place of one register number operand field. The result of this decoding is signals for control of the target functional unit to perform the data processing operation specified by the corresponding instruction on the specified data.

[0051] Central processing unit core **110** includes control registers **114**. Control registers **114** store information for control of the functional units in scalar datapath side A **115** and vector datapath side B **116**. This information could include mode information or the like.

[0052] The decoded instructions from instruction decode unit **113** and information stored in control registers **114** are supplied to scalar datapath side A **115** and vector datapath side B **116**. As a result, functional units within scalar datapath side A **115** and vector datapath side B **116** perform instruction specified data processing operations upon instruction specified data and store the results in an instruction specified data register or registers. Each of scalar datapath side A **115** and vector datapath side B **116** includes plural functional units that may operate in parallel. These will be further detailed below in conjunction with FIG. 2. There is a datapath **117** between scalar datapath side A **115** and vector datapath side B **116** permitting data exchange.

[0053] Central processing unit core **110** includes further non-instruction based modules. Emulation unit **118** permits determination of the machine state of central processing unit core **110** in response to instructions. This capability will typically be employed for algorithmic development.

Interrupts/exceptions unit **119** enables central processing unit core **110** to be responsive to external, asynchronous events (interrupts) and to respond to attempts to perform improper operations (exceptions).

[0054] Central processing unit core **110** includes streaming engine **125**. Streaming engine **125** supplies two data streams from predetermined addresses typically cached in level two combined cache **130** to register files of vector datapath side B. This provides controlled data movement from memory (as cached in level two combined cache **130**) directly to functional unit operand inputs.

This is further detailed below.

[0055] FIG. 1 illustrates data widths of busses between various parts for an example embodiment. Level one instruction cache **121** supplies instructions to the instruction fetch unit **111** via bus **141**. Bus **141** is a 512-bit bus in this example embodiment. Bus **141** is unidirectional from level one instruction cache **121** to central processing unit **110**. Level two combined cache **130** supplies instructions to level one instruction cache **121** via bus **142**. Bus **142** is a 512-bit bus in this example embodiment. Bus **142** is unidirectional from level two combined cache **130** to level one instruction cache **121**.

[0056] Level one data cache **123** exchanges data with register files in scalar datapath side A **115** via bus **143**. Bus **143** is a 64-bit bus in this example embodiment. Level one data cache **123** exchanges data with register files in vector datapath side B **116** via bus **144**. Bus **144** is a 512-bit bus in this example embodiment. Busses **143** and **144** are illustrated as bidirectional supporting both central processing unit **110** data reads and data writes. Level one data cache **123** exchanges data with level two combined cache **130** via bus **145**. Bus **145** is a 512-bit bus in this example embodiment. Bus **145** is illustrated as bidirectional supporting cache service for both central processing unit **110** data reads and data writes.

[0057] As known in the art, CPU data requests are directly fetched from level one data cache **123** upon a cache hit (if the requested data is stored in level one data cache **123**). Upon a cache miss (the specified data is not stored in level one data cache **123**), this data is sought in level two combined cache **130**. The memory locations of this requested data is either a hit in level two combined cache **130** or a miss. A hit is serviced from level two combined cache **130**. A miss is serviced from another level of cache (not illustrated) or from main memory (not illustrated). As is known in the art, the requested instruction may be simultaneously supplied to both level one data cache **123** and central processing unit core **110** to speed use.

[0058] Level two combined cache **130** supplies data of a first data stream to streaming engine **125** via bus **146**. Bus **146** is a 512-bit bus in this example embodiment. Streaming engine **125** supplies data of this first data stream to functional units of vector datapath side B **116** via bus **147**. Bus **147** is a 512-bit bus in this example embodiment. Level two combined cache **130** supplies data of a second data stream to streaming engine **125** via bus **148**. Bus **148** is a 512-bit bus in this example embodiment. Streaming engine **125** supplies data of this second data stream to functional units of vector datapath side B **116** via bus **149**. Bus **149** is a 512-bit bus in this example embodiment. Busses **146**, **147**, **148** and **149** are illustrated as unidirectional from level two combined cache **130** to streaming engine **125** and to vector datapath side B **116** in accordance with this example embodiment.

[0059] Streaming engine data requests are directly fetched from level two combined cache **130** upon a cache hit (if the requested data is stored in level two combined cache **130**). Upon a cache miss (the specified data is not stored in level two combined cache **130**), this data is sought from another level of cache (not illustrated) or from main memory (not illustrated). In some embodiments, level one data cache **123** may cache data not stored in level two combined cache **130**. If such operation is supported, then upon a streaming engine data request that is a miss in level two combined cache **130**, level two combined cache **130** may snoop level one data cache **123** for the streaming engine requested data. If level one data cache **123** stores this data, its snoop response would include the data, which is then supplied to service the streaming engine request. If level one data cache **123** does not store this data, its snoop response would indicate this and level two combined cache **130** would then service this streaming engine request from another level of cache (not illustrated) or from main memory (not illustrated).

[0060] In one embodiment, both level one data cache **123** and level two combined cache **130** may be configured as selected amounts of cache or directly addressable memory in accordance with the aforementioned U.S. Pat. No. 6,606,686 entitled UNIFIED MEMORY SYSTEM ARCHITECTURE INCLUDING CACHE AND DIRECTLY ADDRESSABLE STATIC

[0061] FIG. 2 illustrates further details of functional units and register files within scalar datapath side A **115** and vector datapath side B **116** in accordance with one example embodiment. Scalar datapath side A **115** includes global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213** and D1/D2 local register file **214**. Scalar datapath side A **115** includes L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225** and D2 unit **226**. Vector datapath side B **116** includes global vector register file **231**, L2/S2 local register file **232**, M2/N2/C local register file **233** and predicate register file **234**. Vector datapath side B **116** includes L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245** and P unit **246**. These functional units may be configured to read from or write to certain register files, as will be detailed below.

[0062] L1 unit **221** may accept two 64-bit operands and produce one 64-bit result. The two operands are each recalled from an instruction specified register in either global scalar register file **211** or L1/S1 local register file **212**. L1 unit **221** may perform the following instruction selected operations: 64-bit add/subtract operations; 32-bit min/max operations; 8-bit Single Instruction Multiple Data (SIMD) instructions such as sum of absolute value, minimum and maximum determinations; circular min/max operations; and various move operations between register files. The result produced by L1 unit **221** may be written into an instruction specified register of global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, or D1/D2 local register file **214**.

[0063] S1 unit **222** may accept two 64-bit operands and produce one 64-bit result. The two operands are each recalled from an instruction specified register in either global scalar register file **211** or L1/S1 local register file **212**. In one embodiment, S1 unit **222** may perform the same type of operations as L1 unit **221**. In other embodiments, there may be slight variations between the data processing operations supported by L1 unit **221** and S1 unit **222**. The result produced by S1 unit **222** may be written into an instruction specified register of global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, or D1/D2 local register file **214**.

[0064] M1 unit **223** may accept two 64-bit operands and produce one 64-bit result. The two operands are each recalled from an instruction specified register in either global scalar register file **211** or M1/N1 local register file **213**. M1 unit **223** may perform the following instruction selected operations: 8-bit multiply operations; complex dot product operations; 32-bit bit count operations; complex conjugate multiply operations; and bit-wise Logical Operations, moves, adds, and subtracts. The result produced by M1 unit **223** may be written into an instruction specified register of global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, or D1/D2 local register file **214**.

[0065] N1 unit **224** may accept two 64-bit operands and produce one 64-bit result. The two operands are each recalled from an instruction specified register in either global scalar register file **211** or M1/N1 local register file **213**. N1 unit **224** may perform the same type operations as M1 unit **223**. There may be certain double operations (called dual issued instructions) that employ both the M1 unit **223** and the N1 unit **224** together. The result produced by N1 unit **224** may be written into an instruction specified register of global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, or D1/D2 local register file **214**.

[0066] D1 unit **225** and D2 unit **226** may each accept two 64-bit operands and each produce one 64-bit result. D1 unit **225** and D2 unit **226** may perform address calculations and corresponding load and store operations. D1 unit **225** is used for scalar loads and stores of 64 bits. D2 unit **226** is used for vector loads and stores of 512 bits. D1 unit **225** and D2 unit **226** also may perform: swapping, pack and unpack on the load and store data; 64-bit SIMD arithmetic operations; and 64-bit bit-wise logical operations. D1/D2 local register file **214** will generally store base and offset addresses used in address calculations for the corresponding loads and stores. The two operands are each recalled from an instruction specified register in either global scalar register file **211**, or D1/D2 local register file **214**. The calculated result by D1 unit **225** and/or D2 unit **226** may be

written into an instruction specified register of global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, or D1/D2 local register file **214**.

[0067] L2 unit **241** may accept two 512-bit operands and produce one 512-bit result. Each of up to two operands are each recalled from an instruction specified register in either global vector register file **231**, L2/S2 local register file **232** or predicate register file **234**. L2 unit **241** may perform instruction similar to L1 unit **221** except on wider 512-bit data. The result produced by L2 unit **241** may be written into an instruction specified register of global vector register file **231**, L2/S2 local register file **232**, M2/N2/C local register file **233**, or predicate register file **234**.

[0068] S2 unit **242** may accept two 512-bit operands and produce one 512-bit result. Each of up to two operands are each recalled from an instruction specified register in either global vector register file **231**, L2/S2 local register file **232** or predicate register file **234**. S2 unit **242** may perform instructions similar to S1 unit **222** except on wider 512-bit data. The result produced by S2 unit **242** may be written into an instruction specified register of global vector register file **231**, L2/S2 local register file **232**, M2/N2/C local register file **233**, or predicate register file **234**.

[0069] M2 unit **243** may accept two 512-bit operands and produce one 512-bit result. The two operands are each recalled from an instruction specified register in either global vector register file **231** or M2/N2/C local register file **233**. M2 unit **243** may perform instructions similar to M1 unit **223** except on wider 512-bit data. The result produced by M2 unit **243** may be written into an instruction specified register of global vector register file **231**, L2/S2 local register file **232**, or M2/N2/C local register file **233**.

[0070] N2 unit **244** may accept two 512-bit operands and produce one 512-bit result. The two operands are each recalled from an instruction specified register in either global vector register file **231** or M2/N2/C local register file **233**. N2 unit **244** may perform the same type operations as M2 unit **243**. There may be certain double operations (called dual issued instructions) that employ both M2 unit **243** and the N2 unit **244** together. The result produced by N2 unit **244** may be written into an instruction specified register of global vector register file **231**, L2/S2 local register file **232**, or M2/N2/C local register file **233**.

[0071] C unit **245** may accept two 512-bit operands and produce one 512-bit result. The two operands are each recalled from an instruction specified register in either global vector register file **231** or M2/N2/C local register file **233**. C unit **245** may perform: “Rake” and “Search” instructions; up to 512 2-bit PN*8-bit multiplies; I/Q complex multiplies per clock cycle; 8-bit and 16-bit Sum-of-Absolute-Difference (SAD) calculations, up to 512 SADs per clock cycle; horizontal add and horizontal min/max instructions; and vector permutes instructions. In one embodiment, C unit **245** includes 4 vector control registers (CUCR0 to CUCR3) used to control certain operations of C unit **245** instructions. Control registers CUCR0 to CUCR3 are used as operands in certain C unit **245** operations. For example, control registers CUCR0 to CUCR3 may be used in control of a general permutation instruction (VPERM) or as masks for SIMD multiple DOT product operations (DOTPM) and SIMD multiple Sum-of-Absolute-Difference (SAD) operations. Control register CUCR0 may be used to store polynomials for Galois Field Multiply operations (GFMPY). Control register CUCR1 may be used to store a Galois field polynomial generator function.

[0072] P unit **246** may perform basic logic operations on registers of local predicate register file **234**. P unit **246** has direct access to read from and write to predicate register file **234**. The operations performed by P unit **246** may include AND, ANDN, OR, XOR, NOR, BITR, NEG, SET, BITCNT, RMBD, BIT Decimate and Expand. One use of P unit **246** can include manipulation of an SIMD vector comparison result for use in control of a further SIMD vector operation.

[0073] FIG. 3 illustrates an example embodiment of global scalar register file **211**. In the illustrated embodiment, there are 16 independent 64-bit wide scalar registers designated A0 to A15. Each register of global scalar register file **211** can be read from or written to as 64-bits of scalar data. All scalar datapath side A **115** functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) can read or write to global scalar register file **211**. Global scalar register

file **211** may be read as 32-bits or as 64-bits and may only be written to as 64-bits. The instruction executing determines the read data size. Vector datapath side B **116** functional units (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) can read from global scalar register file **211** via crosspath **117** under restrictions that will be detailed below.

[0074] FIG. **4** illustrates an example embodiment of D1/D2 local register file **214**. In the illustrated embodiment, there are 16 independent 64-bit wide scalar registers designated D0 to D16. Each register of D1/D2 local register file **214** can be read from or written to as 64-bits of scalar data. All scalar datapath side A **115** functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) can write to D1/D2 local register file **214**. Only D1 unit **225** and D2 unit **226** can read from D1/D2 local register file **214**. Data stored in D1/D2 local register file **214** may include base addresses and offset addresses used in address calculations.

[0075] FIG. **5** illustrates an example embodiment of L1/S1 local register file **212**. The embodiment illustrated in FIG. **5** has 8 independent 64-bit wide scalar registers designated AL0 to AL7. Under certain instruction coding formats (see FIG. **13**), L1/S1 local register file **212** can include up to 16 registers. The embodiment of FIG. **5** implements only 8 registers to reduce circuit size and complexity. Each register of L1/S1 local register file **212** can be read from or written to as 64-bits of scalar data. All scalar datapath side A **115** functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) can write to L1/S1 local register file **212**. Only L1 unit **221** and S1 unit **222** can read from L1/S1 local register file **212**.

[0076] FIG. **6** illustrates an example embodiment of M1/N1 local register file **213**. The embodiment illustrated in FIG. **6** has 8 independent 64-bit wide scalar registers designated AM0 to AM7. Under certain instruction coding formats (see FIG. **13**), M1/N1 local register file **213** can include up to 16 registers. The embodiment of FIG. **6** implements only 8 registers to reduce circuit size and complexity. Each register of M1/N1 local register file **213** can be read from or written to as 64-bits of scalar data. All scalar datapath side A **115** functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) can write to M1/N1 local register file **213**. Only M1 unit **223** and N1 unit **224** can read from M1/N1 local register file **213**.

[0077] FIG. **7** illustrates an example embodiment of global vector register file **231**. In the illustrated embodiment, there are 16 independent 512-bit wide vector registers. Each register of global vector register file **231** can be read from or written to as 64-bits of scalar data designated B0 to B15. Each register of global vector register file **231** can be read from or written to as 512-bits of vector data designated VB0 to VB15. The instruction type determines the data size. All vector datapath side B **116** functional units (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) can read or write to global vector register file **231**. Scalar datapath side A **115** functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) can read from global vector register file **231** via crosspath **117** under restrictions that will be detailed below.

[0078] FIG. **8** illustrates an example embodiment of P local register file **234**. In the illustrated embodiment, there are 8 independent 64-bit wide registers designated P0 to P7. Each register of P local register file **234** can be read from or written to as 64-bits of scalar data. Vector datapath side B **116** functional units L2 unit **241**, S2 unit **242**, C unit **244**, and P unit **246** can write to P local register file **234**. Only L2 unit **241**, S2 unit **242**, and P unit **246** can read from P local register file **234**. P local register file **234** may be used for: writing one bit SIMD vector comparison results from L2 unit **241**, S2 unit **242**, or C unit **245**; manipulation of SIMD vector comparison results by P unit **246**; and use of the manipulated results in control of a further SIMD vector operation.

[0079] FIG. **9** illustrates an example embodiment of L2/S2 local register file **232**. The embodiment illustrated in FIG. **9** has 8 independent 512-bit wide vector registers. Under certain instruction coding formats (see FIG. **13**), L2/S2 local register file **232** can include up to 16 registers. The embodiment of FIG. **9** implements only 8 registers to reduce circuit size and complexity. Each register of L2/S2 local vector register file **232** can be read from or written to as 64-bits of scalar

data designated BL0 to BL7. Each register of L2/S2 local vector register file **232** can be read from or written to as 512-bits of vector data designated VBL0 to VBL7. The instruction type determines the data size. All vector datapath side B **116** functional units (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) can write to L2/S2 local register file **232**. Only L2 unit **241** and S2 unit **242** can read from L2/S2 local vector register file **232**.

[0080] FIG. **10** illustrates an example embodiment of M2/N2/C local register file **233**. The embodiment illustrated in FIG. **10** has **8** independent 512-bit wide vector registers. Under certain instruction coding formats (see FIG. **13**), M2/N2/C local register file **233** can include up to 16 registers. The embodiment of FIG. **10** implements only **8** registers to reduce circuit size and complexity. Each register of M2/N2/C local vector register file **233** can be read from or written to as 64-bits of scalar data designated BM0 to BM7. Each register of M2/N2/C local vector register file **233** can be read from or written to as 512-bits of vector data designated VBM0 to VBM7. All vector datapath side B **116** functional units (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) can write to M2/N2/C local vector register file **233**. Only M2 unit **233**, N2 unit **244** and C unit **245** can read from M2/N2/C local vector register file **233**.

[0081] Thus, in accordance with certain disclosed embodiments of this disclosure, global register files may be accessible by all functional units of a side (e.g., scalar and vector) and local register files may be accessible by only some of the functional units of a side. Some additional embodiments in accordance with this disclosure could be practiced employing only one type of register file corresponding to the disclosed global register files.

[0082] Crosspath **117** permits limited exchange of data between scalar datapath side A **115** and vector datapath side B **116**. During each operational cycle one 64-bit data word can be recalled from global scalar register file **211** for use as an operand by one or more functional units of vector datapath side B **116** and one 64-bit data word can be recalled from global vector register file **231** for use as an operand by one or more functional units of scalar datapath side A **115**. Any scalar datapath side A **115** functional unit (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) may read a 64-bit operand from global vector register file **231**. This 64-bit operand is the least significant bits of the 512-bit data in the accessed register of global vector register file **231**. Scalar datapath side A **115** functional units may employ the same 64-bit crosspath data as an operand during the same operational cycle. However, only one 64-bit operand is transferred from vector datapath side B **116** to scalar datapath side A **115** in any single operational cycle. Any vector datapath side B **116** functional unit (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) may read a 64-bit operand from global scalar register file **211**. If the corresponding instruction is a scalar instruction, the crosspath operand data is treated as any other 64-bit operand. If the corresponding instruction is a vector instruction, the upper 448 bits of the operand are zero filled. Vector datapath side B **116** functional units may employ the same 64-bit crosspath data as an operand during the same operational cycle. Only one 64-bit operand is transferred from scalar datapath side A **115** to vector datapath side B **116** in any single operational cycle.

[0083] Streaming engine **125** transfers data in certain circumstances. In the embodiment of FIG. **1**, streaming engine **125** controls two data streams. A stream includes a sequence of elements of a particular type. Programs that operate on streams read the data sequentially, operating on each element in turn. Stream data may have the following basic properties: a well-defined beginning and ending time; fixed element size and type throughout the stream; and a fixed sequence of elements. Thus programs cannot seek randomly within the stream. Further, stream data is read-only while active. Thus, programs cannot write to a stream while simultaneously reading from it. Once a stream is opened, streaming engine **125**: calculates the address; fetches the defined data type from level two unified cache **130** (which may require cache service from a higher level memory, i.e., in the event of a cache miss in level two unified cache **130**); performs data type manipulation (e.g., such as zero extension, sign extension, and/or data element sorting/swapping such as matrix

transposition); and delivers the data directly to the programmed data register file within CPU **110**. Streaming engine **125** is thus useful for real-time digital filtering operations on well-behaved data. Streaming engine **125** frees these memory fetch tasks from the corresponding CPU **110**, thereby enabling the CPU **110** to perform other processing functions.

[0084] Streaming engine **125** provides several benefits. For example, streaming engine **125** permits multi-dimensional memory accesses, increases the available bandwidth to functional units of CPU **110**, reduces the number of cache miss stalls since the stream buffer bypasses level one data cache **123**, reduces the number of scalar operations required to maintain a loop, and manages address pointers. Streaming engine **125** can also handle address generation, which frees up address generation instruction slots and D1 unit **225** and D2 unit **226** for other computations.

[0085] CPU **110** operates on an instruction pipeline. Instructions are fetched in instruction packets of a fixed length as further described below. All instructions have the same number of pipeline phases for fetch and decode, but can have a varying number of execute phases.

[0086] FIG. **11** illustrates an example embodiment of an instruction pipeline having the following pipeline phases: program fetch phase **1110**, dispatch and decode phases **1120**, and execution phase **1130**. Program fetch phase **1110** includes three stages for all instructions. Dispatch and decode phases **1120** include three stages for all instructions. Execution phase **1130** includes one to four stages dependent on the instruction.

[0087] Fetch phase **1110** includes program address generation stage **1111** (PG), program access stage **1112** (PA), and program receive stage **1113** (PR). During program address generation stage **1111** (PG), a program address is generated in the CPU and a read request is sent to a memory controller for the level one instruction cache L1I. During the program access stage **1112** (PA), the level one instruction cache L1I processes the request, accesses the data in its memory, and sends a fetch packet to the CPU boundary. During the program receive stage **1113** (PR), the CPU registers the fetch packet.

[0088] In an example embodiment, instructions are fetched as sixteen 32-bit wide slots, constituting a fetch packet, at a time. FIG. **12** illustrates one such embodiment, where a single fetch packet includes sixteen instructions **1201** to **1216**. Fetch packets are aligned on 512-bit (16-word) boundaries. The fetch packet, in one embodiment, employs a fixed 32-bit instruction length. Fixed length instructions are advantageous for several reasons. Fixed length instructions enable easy decoder alignment. A properly aligned instruction fetch can load plural instructions into parallel instruction decoders. Such a properly aligned instruction fetch can be achieved by predetermined instruction alignment when stored in memory (fetch packets aligned on 512-bit boundaries) coupled with a fixed instruction packet fetch. An aligned instruction fetch also permits operation of parallel decoders on instruction-sized fetched bits. Variable length instructions may require an initial step of locating each instruction boundary before they can be decoded. A fixed length instruction set generally permits more regular layout of instruction fields. This simplifies the construction of each decoder which is an advantage for a wide issue VLIW central processor.

[0089] The execution of the individual instructions is partially controlled by a p bit in each instruction. This p bit can be configured as bit **0** of the 32-bit wide slot. The p bit of an instruction determines whether the instruction executes in parallel with a next instruction. Instructions are scanned from lower to higher addresses. If the p bit of an instruction is 1, then the next following instruction (higher memory address) is executed in parallel with (in the same cycle as) that instruction. If the p bit of an instruction is 0, then the next following instruction is executed in the cycle after the instruction.

[0090] CPU **110** and level one instruction cache L1I **121** pipelines are de-coupled from each other. Fetch packet returns from level one instruction cache L1I can take different number of clock cycles, depending on external circumstances such as whether there is a hit in level one instruction cache **121** or a hit in level two combined cache **130**. Therefore program access stage **1112** (PA) can take several clock cycles instead of 1 clock cycle as in the other stages.

[0091] The instructions executing in parallel constitute an execute packet. In one embodiment, an execute packet can contain up to sixteen instructions (slots). No two instructions in an execute packet may use the same functional unit. A slot can be one of five types: 1) a self-contained instruction executed on one of the functional units of CPU **110** (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, D2 unit **226**, L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**); 2) a unitless instruction such as a NOP (no operation) instruction or multiple NOP instructions; 3) a branch instruction; 4) a constant field extension; and 5) a conditional code extension. Some of these slot types will be further explained below.

[0092] Dispatch and decode phases **1120** include instruction dispatch to appropriate execution unit stage **1121** (DS), instruction pre-decode stage **1122** (DC1), and instruction decode, operand reads stage **1123** (DC2). During instruction dispatch to appropriate execution unit stage **1121** (DS) the fetch packets are split into execute packets and assigned to the appropriate functional units. During the instruction pre-decode stage **1122** (DC1), the source registers, destination registers, and associated paths are decoded for the execution of the instructions in the functional units. During the instruction decode, operand reads stage **1123** (DC2), more detailed unit decodes are done, as well as reading operands from the register files.

[0093] Execution phase **1130** includes execution stages **1131** to **1135** (E1 to E5). Different types of instructions may require different numbers of these stages to complete their execution. These stages of the pipeline play an important role in understanding the device state at CPU cycle boundaries.

[0094] During execute 1 stage **1131** (E1), the conditions for the instructions are evaluated and operands are operated on. As illustrated in FIG. **11**, execute 1 stage **1131** may receive operands from a stream buffer **1141** and one of the register files shown schematically as **1142**. For load and store instructions, address generation is performed and address modifications are written to a register file. For branch instructions, a branch fetch packet in PG phase is affected.

[0095] As illustrated in FIG. **11**, load and store instructions access memory, shown here schematically as memory **1151**. For single-cycle instructions, results are written to a destination register file. This assumes that any conditions for the instructions are evaluated as true. If a condition is evaluated as false, the instruction does not write any results or have any pipeline operation after execute 1 stage **1131**.

[0096] During execute 2 stage **1132** (E2), load instructions send the address to memory. Store instructions send the address and data to memory. Single-cycle instructions that saturate results set a bit (SAT) in the control status register (CSR) if saturation occurs. For 2-cycle instructions, results are written to a destination register file.

[0097] During execute 3 stage **1133** (E3), data memory accesses are performed. Any multiply instructions that saturate results set the SAT bit in the control status register (CSR) if saturation occurs. For 3-cycle instructions, results are written to a destination register file.

[0098] During execute 4 stage **1134** (E4), load instructions bring data to the CPU boundary. For 4-cycle instructions, results are written to a destination register file.

[0099] During execute 5 stage **1135** (E5), load instructions write data into a register. This is illustrated schematically in FIG. **11** with input from memory **1151** to execute 5 stage **1135**.

[0100] FIG. **13** illustrates an instruction coding format **1300** of functional unit instructions in accordance with an example embodiment. Those skilled in the art would realize that other instruction codings are feasible and within the scope of this disclosure. In the illustrated embodiment, each instruction includes 32 bits and controls the operation of one of the individually controllable functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, D2 unit **226**, L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**). The bit fields of instruction coding **1300** are defined as follows.

[0101] The creg field **1301** (bits **29** to **31**) and the z bit **1302** (bit **28**) are fields used in conditional instructions. These bits are used for conditional instructions to identify a predicate (also referred to as “conditional”) register and a condition. The z bit **1302** (bit **28**) indicates whether the condition is

based upon zero or not zero in the predicate register. If z=1, the test is for equality with zero. If z=0, the test is for nonzero. For unconditional instructions, the creg field **1301** and z bit **1302** are set to all 0s to allow unconditional instruction execution. The creg field **1301** and the z field **1302** are encoded in the instruction as shown in Table 1.

TABLE-US-00001 TABLE 1 Conditional creg z Register 31 30 29 28 Unconditional 0 0 0 0
Reserved 0 0 0 1 A0 0 0 1 z A1 0 1 0 z A2 0 1 1 z A3 1 0 0 z A4 1 0 1 z A5 1 1 0 z Reserved 1 1 x x
[0102] Execution of a conditional instruction is conditional upon the value stored in the specified conditional data register. In this illustrated example, the conditional register is a data register in the global scalar register file **211**. The “z” in the z bit column refers to the zero/not zero comparison selection noted above, and “x” is a do not care state. In this example, the use of three bits for the creg field **1301** in this coding allows for specifying only a subset (A0-A5) of the 16 global registers of global scalar register file **211** as predicate registers. This selection was made to preserve bits in the instruction coding and reduce opcode space.

[0103] The dst field **1303** (bits **23** to **27**) specifies a register in a corresponding register file as the destination of the instruction results (e.g., where the results are to be written).

[0104] The src2/cst field **1304** (bits **18** to **22**) can be interpreted in different ways depending on the instruction opcode field (bits **4** to **12** for all instructions and additionally bits **28** to **31** for unconditional instructions). The src2/cst field **1304** indicates a second source operand, either from a register of a corresponding register file or as a constant depending on the instruction opcode field. Depending on the instruction type, when the second source operand is a constant, this may be treated as an unsigned integer and zero extended to a specified data length or may be treated as a signed integer and sign extended to the specified data length.

[0105] The src1 field **1305** (bits **13** to **17**) specifies a register in a corresponding register file as a first source operand.

[0106] The opcode field **1306** (bits **4** to **12**) for all instructions (and additionally bits **28** to **31** for unconditional instructions) specifies the type of instruction and designates appropriate instruction options. This includes designation of the functional unit used and the operation performed. Additional details regarding such instruction options are detailed below.

[0107] The e bit **1307** (bit **2**) is used for immediate constant instructions where the constant may be extended. If e=1, then the immediate constant is extended in a manner detailed below. If e=0, then the immediate constant is not extended. In the latter case, the immediate constant is specified by the src2/cst field **1304** (bits **18** to **22**). The e bit **1307** may be used for only some types of instructions. Accordingly, with proper coding, the e bit **1307** may be omitted from instructions which do not need it, and this bit can instead be used as an additional opcode bit.

[0108] The s bit **1308** (bit **1**) designates scalar datapath side A **115** or vector datapath side B **116**. If s=0, then scalar datapath side A **115** is selected, and the available functional units (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225**, and D2 unit **226**) and register files (global scalar register file **211**, L1/S1 local register file **212**, M1/N1 local register file **213**, and D1/D2 local register file **214**) will be those corresponding to scalar datapath side A **115** as illustrated in FIG. 2. Similarly, s =1 selects vector datapath side B **116**, and the available functional units (L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244**, C unit **245**, and P unit **246**) and register files (global vector register file **231**, L2/S2 local register file **232**, M2/N2/C local register file **233**, and predicate local register file **234**) will be those corresponding to vector datapath side B **116** as illustrated in FIG. 2.

[0109] The p bit **1308** (bit **0**) is used to determine whether the instruction executes in parallel with the following instruction. The p-bits are scanned from lower to higher addresses. If p=1 for the current instruction, then the next instruction executes in parallel with the current instruction. If p=0 for the current instruction, then the next instruction executes in the cycle after the current instruction. All instructions executing in parallel constitute an execute packet. In one example embodiment, an execute packet can contain up to twelve instructions for parallel execution, with each instruction in an execute packet assigned to a different functional unit.

[0110] In one example embodiment of processor **100**, there are two different condition code extension slots (slot 0 and slot 1). The condition code extension slots may be 32-bit in this example embodiment, as with the coding format **1300** described in FIG. **13**. Each execute packet can contain one each of these 32-bit condition code extension slots, which contains the 4-bit creg/z fields (e.g., similar to bits **28** to **31** of coding **1300**) for the instructions in the same execute packet. FIG. **14** illustrates an example coding for condition code extension slot 0 and FIG. **15** illustrates an example coding for condition code extension slot 1.

[0111] FIG. **14** illustrates an example coding **1400** for condition code extension slot 0. Field **1401** (bits **28** to **31**) specify 4 creg/z bits assigned to the L1 unit **221** instruction in the same execute packet. Field **1402** (bits **27** to **24**) specify 4 creg/z bits assigned to the L2 unit **241** instruction in the same execute packet. Field **1403** (bits **19** to **23**) specify 4 creg/z bits assigned to the S1 unit **222** instruction in the same execute packet. Field **1404** (bits **16** to **19**) specify 4 creg/z bits assigned to the S2 unit **242** instruction in the same execute packet. Field **1405** (bits **12** to **15**) specify 4 creg/z bits assigned to the D1 unit **225** instruction in the same execute packet. Field **1406** (bits **8** to **11**) specify 4 creg/z bits assigned to the D2 unit **226** instruction in the same execute packet. Field **1407** (bits **6** and **7**) is unused/reserved. Field **1408** (bits **0** to **5**) is coded with a set of unique bits (CCEX0) to identify the condition code extension slot 0. Once this unique ID of condition code extension slot 0 is detected, the corresponding creg/z bits are employed to control conditional execution of any L1 unit **221**, L2 unit **241**, S1 unit **222**, S2 unit **242**, D1 unit **225**, and D2 unit **226** instructions in the same execution packet. These creg/z bits are interpreted as shown in Table 1. If the corresponding instruction is conditional (e.g., creg/z bits are not all 0) the corresponding bits in the condition code extension slot 0 override the condition code bits (bits **28** to **31** of creg field **1301** and z bit **1302**) in the instruction (e.g., coded using coding format **1300**). In the illustrated example, no execution packet can have more than one instruction directed to a particular execution unit, and no execute packet of instructions can contain more than one condition code extension slot 0. Thus, the mapping of creg/z bits to functional unit instructions is unambiguous. As discussed above, setting the creg/z bits equal to “0000” makes the instruction unconditional. Thus, a properly coded condition code extension slot 0 can make some corresponding instructions conditional and some unconditional.

[0112] FIG. **15** illustrates an example coding **1500** for condition code extension slot 1. Field **1501** (bits **28** to **31**) specify 4 creg/z bits assigned to the M1 unit **223** instruction in the same execute packet. Field **1502** (bits **27** to **24**) specify 4 creg/z bits assigned to the M2 unit **243** instruction in the same execute packet. Field **1503** (bits **19** to **23**) specify 4 creg/z bits assigned to the C unit **245** instruction in the same execute packet. Field **1504** (bits **16** to **19**) specify 4 creg/z bits assigned to the N1 unit **224** instruction in the same execute packet. Field **1505** (bits **12** to **15**) specify 4 creg/z bits assigned to the N2 unit **244** instruction in the same execute packet. Field **1506** (bits **6** to **11**) is unused/reserved. Field **1507** (bits **0** to **5**) is coded with a set of unique bits (CCEX1) to identify the condition code extension slot 1. Once this unique ID of condition code extension slot 1 is detected, the corresponding creg/z bits are employed to control conditional execution of any M1 unit **223**, M2 unit **243**, C unit **245**, N1 unit **224** and N2 unit **244** instructions in the same execution packet. These creg/z bits are interpreted as shown in Table 1. If the corresponding instruction is conditional (e.g., creg/z bits are not all 0) the corresponding bits in the condition code extension slot 1 override the condition code bits (bits **28** to **31** of creg field **1301** and z bit **1302**) in the instruction (e.g., coded using coding format **1300**). In the illustrated example, no execution packet can have more than one instruction directed to a particular execution unit, and no execute packet of instructions can contain more than one condition code extension slot 1. Thus, the mapping of creg/z bits to functional unit instruction is unambiguous. As discussed above, setting the creg/z bits equal to “0000” makes the instruction unconditional. Thus, a properly coded condition code extension slot 1 can make some instructions conditional and some unconditional.

[0113] Both condition code extension slot 0 **1400** and condition code extension slot 1 may include

a p bit to define an execute packet as described above in conjunction with FIG. 13. In one example embodiment, as illustrated in FIGS. 14 and 15, bit 0 of code extension slot 0 1400 and condition code extension slot 1 1500 may provide the p bit. Assuming the p bit for the code extension slots 1400, 1500 is always encoded as 1 (parallel execution), neither code extension slot 1400, 1500 should be the last instruction slot of an execute packet.

[0114] In one example embodiment of processor 100, there are two different constant extension slots. Each execute packet can contain one each of these unique 32-bit constant extension slots which contains 27 bits to be concatenated as high order bits with a 5-bit constant field in the instruction coding 1300 to form a 32-bit constant. As noted in the instruction coding 1300 description above, only some instructions define the 5-bit src2/cst field 1304 as a constant rather than a source register identifier. At least some of those instructions may employ a constant extension slot to extend this constant to 32 bits.

[0115] FIG. 16 illustrates an example coding 1600 of constant extension slot 0. Each execute packet may include one instance of constant extension slot 0 and one instance of constant extension slot 1. FIG. 16 illustrates that constant extension slot 0 1600 includes two fields. Field 1601 (bits 5 to 31) constitute the most significant 27 bits of an extended 32-bit constant with the target instruction scr2/cst field 1304 providing the five least significant bits. Field 1602 (bits 0 to 4) are coded a set of unique bits (CSTX0) to identify the constant extension slot 0. In an example embodiment constant extension slot 0 1600 is used to extend the constant of one of an L1 unit 221 instruction, data in a D1 unit 225 instruction, an S2 unit 242 instruction, an offset in a D2 unit 226 instruction, an M2 unit 243 instruction, an N2 unit 244 instruction, a branch instruction, or a C unit 245 instruction in the same execute packet. Constant extension slot 1 is similar to constant extension slot 0 except that bits 0 to 4 are coded a set of unique bits (CSTX1) to identify the constant extension slot 1. In an example embodiment, constant extension slot 1 is used to extend the constant of one of an L2 unit 241 instruction, data in a D2 unit 226 instruction, an S1 unit 222 instruction, an offset in a D1 unit 225 instruction, an M1 unit 223 instruction, or an N1 unit 224 instruction in the same execute packet.

[0116] Constant extension slot 0 and constant extension slot 1 are used as follows. The target instruction must be of the type permitting constant specification. As known in the art this is implemented by replacing one input operand register specification field with the least significant bits of the constant as described above with respect to scr2/cst field 1304. Instruction decoder 113 determines this case, known as an immediate field, from the instruction opcode bits. The target instruction also includes one constant extension bit (e bit 1307) dedicated to signaling whether the specified constant is not extended (e.g., constant extension bit=0) or the constant is extended (e.g., constant extension bit=1). If instruction decoder 113 detects a constant extension slot 0 or a constant extension slot 1, it further checks the other instructions within that execute packet for an instruction corresponding to the detected constant extension slot. A constant extension is made when a corresponding instruction has a constant extension bit (e bit 1307) equal to 1.

[0117] FIG. 17 is a block diagram 1700 illustrating constant extension logic that may be implemented in processor 100. FIG. 17 assumes that instruction decoder 113 detects a constant extension slot and a corresponding instruction in the same execute packet. Instruction decoder 113 supplies the 27 extension bits from the constant extension slot (bit field 1601) and the 5 constant bits (bit field 1304) from the corresponding instruction to concatenator 1701. Concatenator 1701 forms a single 32-bit word from these two parts. In the illustrated embodiment, the 27 extension bits from the constant extension slot (bit field 1601) are the most significant bits and the 5 constant bits (bit field 1305) are the least significant bits. This combined 32-bit word is supplied to one input of multiplexer 1702. The 5 constant bits from the corresponding instruction field 1305 supply a second input to multiplexer 1702. Selection of multiplexer 1702 is controlled by the status of the constant extension bit. If the constant extension bit (e bit 1307) is 1 (extended), multiplexer 1702 selects the concatenated 32-bit input. If the constant extension bit is 0 (not extended), multiplexer

1702 selects the 5 constant bits from the corresponding instruction field **1305**. Multiplexer **1702** supplies this output to an input of sign extension unit **1703**.

[0118] Sign extension unit **1703** forms the final operand value from the input from multiplexer **1703**. Sign extension unit **1703** receives control inputs Scalar/Vector and Data Size. The Scalar/Vector input indicates whether the corresponding instruction is a scalar instruction or a vector instruction. The functional units of data path side A **115** (L1 unit **221**, S1 unit **222**, M1 unit **223**, N1 unit **224**, D1 unit **225** and D2 unit **226**) are, in this embodiment, limited to performing scalar instructions. Any instruction directed to one of these functional units is a scalar instruction. Data path side B functional units L2 unit **241**, S2 unit **242**, M2 unit **243**, N2 unit **244** and C unit **245** may perform scalar instructions or vector instructions. Instruction decoder **113** determines whether the instruction is a scalar instruction or a vector instruction from the opcode bits. P unit **246** may only perform scalar instructions in this embodiment. The Data Size may be 8 bits (byte B), 16 bits (half-word H), 32 bits (word W), 64 bits (double word D), quad word (128 bit) data or half vector (256 bit) data.

[0119] Table 2 lists the operation of sign extension unit **1703** for the various options.

TABLE-US-00002

TABLE 2	Instruction	Operand	Constant	Type	Size	Length	Action
Scalar	B/H/W/D	5 bits	Sign extend	to 64 bits	Scalar	B/H/W/D	32 bits
Sign extend	to 64 bits	Vector	B/H/W/D	5 bits	Sign extend	to operand size and replicate across the whole vector	Vector
Vector	B/H/W	32 bits	Replicate	32-bit constant across each 32-bit (W) lane	Vector	D	32 bits
Sign extend	to 64 bits	and replicate across each 64-bit (D) lane					

[0120] Both constant extension slot 0 and constant extension slot 1 may include a p bit to define an execute packet as described above in conjunction with FIG. **13**. In one example embodiment, as in the case of the condition code extension slots, bit **0** of constant extension slot 0 and constant extension slot 1 may provide the p bit. Assuming the p bit for constant extension slot 0 and constant extension slot 1 is always encoded as 1 (parallel execution), neither constant extension slot 0 nor constant extension slot 1 should be in the last instruction slot of an execute packet.

[0121] In some embodiments, an execute packet can include a constant extension slot 0 or 1 and more than one corresponding instruction marked constant extended (e bit=1). For constant extension slot 0, this would mean more than one of an L1 unit **221** instruction, data in a D1 unit **225** instruction, an S2 unit **242** instruction, an offset in a D2 unit **226** instruction, an M2 unit **243** instruction, or an N2 unit **244** instruction in an execute packet have an e bit of 1. For constant extension slot 1 this would mean more than one of an L2 unit **241** instruction, data in a D2 unit **226** instruction, an S1 unit **222** instruction, an offset in a D1 unit **225** instruction, an M1 unit **223** instruction or an N1 unit **224** instruction in an execute packet have an e bit of 1. In such instances, instruction decoder **113** may, in one embodiment, determine this case an invalid and unsupported operation. In another embodiment, this combination may be supported with extension bits of the constant extension slot applied to each corresponding functional unit instruction marked constant extended.

[0122] Special vector predicate instructions use registers in predicate register file **234** to control vector operations. In the current embodiment, all the SIMD vector predicate instructions operate on selected data sizes. The data sizes may include byte (8 bit) data, half word (16 bit) data, word (32 bit) data, double word (64 bit) data, quad word (128 bit) data and half vector (256 bit) data. Each bit of the predicate register controls whether a SIMD operation is performed upon the corresponding byte of data. The operations of P unit **246** permit a variety of compound vector SIMD operations based upon more than one vector comparison. For example, a range determination can be made using two comparisons. A candidate vector is compared with a first vector reference having the minimum of the range packed within a first data register. A second comparison of the candidate vector is made with a second reference vector having the maximum of the range packed within a second data register. Logical combinations of the two resulting predicate registers would permit a vector conditional operation to determine whether each data part of the

candidate vector is within range or out of range.

[0123] L1 unit **221**, S1 unit **222**, L2 unit **241**, S2 unit **242** and C unit **245** often operate in a single instruction multiple data (SIMD) mode. In this SIMD mode, the same instruction is applied to packed data from the two operands. Each operand holds plural data elements disposed in predetermined slots. SIMD operation is enabled by carry control at the data boundaries. Such carry control enables operations on varying data widths.

[0124] FIG. **18** illustrates the carry control. AND gate **1801** receives the carry output of bit N within the operand wide arithmetic logic unit (64 bits for scalar datapath side A **115** functional units and **512** bits for vector datapath side B **116** functional units). AND gate **1801** also receives a carry control signal which will be further explained below. The output of AND gate **1801** is supplied to the carry input of bit N+1 of the operand wide arithmetic logic unit. AND gates such as AND gate **1801** are disposed between every pair of bits at a possible data boundary. For example, for 8-bit data, such an AND gate will be between bits **7** and **8**, bits **15** and **16**, bits **23** and **24**, etc. Each such AND gate receives a corresponding carry control signal. If the data size is of the minimum, then each carry control signal is 0, effectively blocking carry transmission between the adjacent bits. The corresponding carry control signal is 1 if the selected data size requires both arithmetic logic unit sections. Table 3 below shows example carry control signals for the case of a 512-bit wide operand, such as used by vector datapath side B **116** functional units, which may be divided into sections of 8 bits, 16 bits, 32 bits, 64 bits, 128 bits, or 256 bits. In Table 3 the upper 32 bits control the upper bits (bits **128** to **511**) carries and the lower **32** bits control the lower bits (bits **0** to **127**) carries. No control of the carry output of the most significant bit is needed, thus only 63 carry control signals are required.

TABLE-US-00003 TABLE 3 Data Size Carry Control Signals 8 bits (B) –000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 0000 16 bits (H) –101 0101 0101
0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 0101 32 bits (W) –111 0111
0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 0111 64 bits (D) –111 1111
0111 1111 0111 1111 0111 1111 0111 1111 0111 1111 0111 1111 0111 1111 128 bits –111 1111 1111
1111 0111 1111 1111 1111 0111 1111 1111 1111 0111 1111 1111 1111 256 bits –111 1111 1111 1111
1111 1111 1111 1111 0111 1111 1111 1111 1111 1111 1111 1111 1111 1111

[0125] It is typical in the art to operate on data sizes that are integral powers of 2 (2N). However, this carry control technique is not limited to integral powers of 2. One skilled in the art would understand how to apply this technique to other data sizes and other operand widths.

[0126] Processor **100** includes dedicated instructions to perform table look up operations implemented via one of D1 unit **225** or D2 unit **226**. The tables for these table look up operations are mapped into level one data cache **123** directly addressable memory. An example of such a table/cache configuration is disclosed in accordance with U.S. Pat. No. 6,606,686 entitled UNIFIED MEMORY SYSTEM ARCHITECTURE INCLUDING CACHE AND DIRECTLY ADDRESSABLE STATIC RANDOM ACCESS MEMORY. These tables may be loaded by normal memory operations, such as via a direct memory access (DMA) port, by a special purpose LUTINIT instruction (described below), or just a normal store instruction to the memory space containing the tables. In one example embodiment, processor **100** supports up to 4 separate sets of parallel look up tables and, within a set, up to 16 tables can be looked up in parallel with byte, half word or word element sizes. In accordance with this embodiment, at least the portion of level one data cache **123** devoted to directly addressed memory has 16 banks. This permits parallel access to 16 memory locations and supports up to 16 tables per table set.

[0127] These look up tables are accessed with independently specified base and index addresses. A look up table base address register (LTBR) specifies the base address for each set of parallel tables. Each look up table instruction contains a set number identifying which base address register to use for that instruction. Based upon the use of a directly addressable portion of the level one data cache **123**, each base address should align with the cache line size of the level one data cache **123**. In one

embodiment, the cache line size may be 128 bytes.

[0128] A look up table configuration register for each set of parallel tables sets controls information to the corresponding set of tables. FIG. 19 illustrates the data fields of an example look up table configuration register 1900. Promotion field 1901 (bits 24 and 25) sets the type of promotion upon storage of elements into a vector register. Promotion field 1901 is decoded as shown in Table 4.

Promotion	Description
00	No promotion
01	2× Promotion
10	4× Promotion
11	8× Promotion

[0129] A field 1901 coding of 00 designates no promotion. A field 1901 coding of 01 designates a 2× promotion. A field 1901 coding of 10 designates a 4× promotion. A field 1901 coding of 11 designates an 8× promotion. In one example embodiment, the promoted data is limited to data sizes up to a double-word size (64 bits). Thus, in such an embodiment: a 2× promotion is valid for a data element size of byte (promoted from byte (8 bits) to half word (16 bits), half word (promoted from half word (16 bits) to word (32 bits), and word (promoted from word (32 bits) to double-word (64 bits); a 4× promotion is valid for a data element size of byte (promoted from byte (8 bit) to word (32 bit) and half word (promoted from half word (16 bit) to double-word (64 bit); and an 8× promotion is only valid for a data element size of byte (promoted from byte (8 bit) to double-word (64 bit). Promotion will be further explained below.

[0130] Table size field 1902 (bits 16 to 23) sets the table size. Table Size field 1902 is decoded as shown in Table 5.

Size	Description
0000	0.0 Kbytes
0001	1.0 Kbytes
0010	2.0 Kbytes
0011	4.0 Kbytes
0100	8.0 Kbytes
0101	16.0 Kbytes
0110	32.0 Kbytes
0111-1111	Reserved

[0131] The table base address stored in the corresponding look up table base address register must be aligned to the table size specified in the look up table configuration register.

[0132] Weight Size (WSIZE) field 1903 (bits 11 to 13) indicates the size of weight values in a source register for weighted histogram operations, described in further detail below. Weight Size field 1903 is decoded as shown in Table 6.

Weight Size	Description
000	Byte/8 bits
001	Half word/16 bits
010-111	Reserved

[0133] Interpolation field 1904 (bits 8 to 10) indicates a number of successive elements written to a destination register in response to a look up table read instruction, described in further detail below. Interpolation field 1904 is decoded as shown in Table 7.

Interpolation	Description
000	No interpolation, only indexed element per table is written
001	Returns 2 elements per table
010	Returns 4 elements per table
011	Returns 8 elements per table
100-111	Reserved

[0134] An interpolation field 1904 coding of 000 designates no interpolation, where only the indexed element per table is written from the look up table to a destination register. An interpolation field 1904 coding of 001 designates interpolating 2 elements, where the indexed element and an additional, adjacent element per table are written from the look up table into the destination register. An interpolation field 1904 coding of 010 designates interpolating 4 elements, where the indexed element and an additional, adjacent 3 elements per table are written from the look up table into the destination register. An interpolation field 1904 coding of 011 designates interpolating 8 elements, where the indexed element and an additional, adjacent 7 elements per table are written from the look up table into the destination register. In one example embodiment, the interpolation field 1904 (in conjunction with the number of tables field 1908, explained below) cannot exceed the maximum number of elements that can be returned by L1D 123, which in one example is 16 elements. Thus, in such an embodiment, no interpolation is possible when the number of tables field 1908 indicates 16 tables; a maximum of 2-element interpolation is possible when the number of tables field 1908 indicates 8 tables; a maximum of 4-element interpolation is possible when the number of tables field 1908 indicates 4 tables; and a maximum of 8-element

interpolation is possible when the number of tables field **1908** indicates 2 tables or 1 table.

[0135] Saturation (SAT) field **1905** (bit 7) indicates whether to saturate histogram bin entries to min/max values in response to a histogram operation, described in further detail below. If the saturation field **1905** is 1, then histogram bin entries are saturated to min/max values of the element data type. For example, unsigned bytes saturate to [0, 0xFF]; signed bytes saturate to [0x80, 0x7F]; unsigned half-words saturate to [0, 0xFFFF]; signed half-words saturate to [0x8000, 0x7FFF]; unsigned words saturate to [0, 0xFFFF FFFF]; and signed words saturate to [0x8000 0000, 0x7FFF FFFF]. If the saturation field 1905 is 0, then histogram bin entries do not saturate to min/max values of the element data type and instead will wrap around when incremented or decremented beyond a minimum value or maximum value, respectively.

[0136] Signed field **1906** (bit 6) indicates whether processor **100** treats the recalled look up table elements as signed integers or unsigned integers. If the signed field **1906** is 1, processor **100** treats the look up table elements as signed integers. If the signed field **1906** is 0, processor **100** treats the look up table elements as unsigned integers.

[0137] Element Size (ESIZE) field **1907** (bits 3 to 5) indicate the look up table element size. Element Size field **1907** is decoded as shown in Table 8.

TABLE-US-00008 TABLE 8 ELEMENT SIZE Description 000 byte/8 bits 001 half word/16 bits 010 word/32 bits 011-111 reserved

[0138] Number of Tables (NTBL) field **1908** (bits 0 to 2) indicates the number of tables to be looked up in parallel. Number of Tables field **1908** is decoded as shown in Table 9.

TABLE-US-00009 TABLE 9 NUMBER OF TABLES Description 000 1 table 001 2 tables 010 4 tables 011 8 tables 100 16 tables 101-111 reserved

[0139] A look up table enable register **2000** specifies the type of operations permitted for a particular table set. This is illustrated in FIG. 20. As shown in FIG. 20, this example employs a field in a single register to control a corresponding one of the four table sets. Field **2001** controls table set 3. Field **2002** controls table set 2. Field **2003** controls table set 1. Field **2004** controls table set 0. Table Enable fields **2001**, **2002**, **2003** and **2004** are each decoded as shown in Table 10.

TABLE-US-00010 TABLE 10 TABLE ENABLE Description 00 no look up table operations 01 read operations allowed 10 reserved 11 read and write operations allowed

[0140] If the table set field is 01, then read operations are permitted from the corresponding look up table base address register and the corresponding look up table configuration register. If the table set field is 11, then read operations are permitted from and write operations are permitted to the corresponding look up table base address register and the corresponding look up table configuration register. If the table set field is 00, then no look up table operations are permitted.

[0141] Each look up table instruction specifies a vector register as an operand. This vector register is treated as a set of 32-bit look up table indices by the look up table operation corresponding to the instruction. Table 11 shows the coding of the vector indices in the vector operand register based upon the number tables for the set of tables controlled by Number of Tables field **1908** of the corresponding look up table configuration register.

TABLE-US-00011 TABLE 11 Vector 1 2 4 8 16 Register bits Index Table Tables tables tables tables Vx[31:0] index0 valid valid valid valid valid Vx[63:32] index1 — valid valid valid valid Vx[95:64] index2 — — valid valid valid Vx[127:96] index3 — — valid valid valid Vx[159:128] index4 — — — valid valid Vx[191:160] index5 — — — valid valid Vx[223:192] index6 — — — valid valid Vx[255:224] index7 — — — valid valid Vx[287:256] index8 — — — — valid Vx[319:288] index9 — — — — valid Vx[351:320] index10 — — — — valid Vx[383:352] index11 — — — — valid Vx[415:384] index12 — — — — valid Vx[447:416] index13 — — — — valid Vx[479:448] index14 — — — — valid Vx[511:480] index15 — — — — valid

[0142] Depending upon the number of tables specified in the Number of Tables field **1908** of the corresponding look up table configuration register **1900**, the vector register bits specify various indices. The address for a table element within the first table for look up table operation is the base

address stored in the base address register plus the index specified by bits **0** to **31** of the vector register values. The address for a table element within the second table for look up table operation (assuming at least two tables are specified by number of tables field **1908**) is the base address stored in the base address register plus the index specified by bits **32** to **63** of the vector register. Similarly, the vector register specifies an offset for each table specified.

[0143] FIG. **21** illustrates look up table organization when the corresponding look up table configuration register **1900** specifies one table for that table set. Level one data cache **123** includes a portion of directly addressable memory, including portion **2111** below the look up table, the look up table, and a portion **2112** above the look up table. The corresponding look up table set base address register **2101** specifies the beginning of the table set. In the example of FIG. **21**, the number of tables field **1908** specifies a single table. The end of the memory allocated to the table set is specified by the table size field **1902**. Index source register **2102** specifies a single offset (index iA) used to address the table. As shown in FIG. **21**, the single table employs all **16** banks of memory.

[0144] FIG. **22** illustrates look up table organization when the corresponding look up table configuration register **1900** specifies two tables for that table set. The look up table set base address register **2101** specifies the beginning of the table set. The number of tables field **1908** specifies two tables. The end of the memory allocated to the table set is specified by the table size field **1902**. Index source register **2102** specifies two offsets used to address the tables. A first index iA addresses Table 1 and a second index iB addresses Table 2. Table 1 data is stored in memory banks **1** to **8**. Table 2 data is stored in memory banks **9** to **16**.

[0145] FIG. **23** illustrates look up table organization when the corresponding look up table configuration register **1900** specifies four tables for that table set. The look up table set base address register **2101** specifies the beginning of the table set. The number of tables field **1908** specifies four tables. The end of the memory allocated to the table set is specified by the table size field **1902**. Index source register **2102** specifies four offsets used to address the tables. A first index iA addresses Table 1, a second index iB addresses Table 2, a third index iC addresses Table 3 and a fourth index iD addresses Table 4. Table 1 data is stored in memory banks **1** to **4**. Table 2 data is stored in memory banks **5** to **8**. Table 3 data is stored in memory banks **9** to **12**. Table 4 data is stored in memory banks **13** to **16**.

[0146] FIG. **24** illustrates look up table organization when the corresponding look up table configuration register **1900** specifies eight tables for that table set. The look up table set base address register **2101** specifies the beginning of the table set. The number of tables field **1908** specifies eight tables. The end of the memory allocated to the table set is specified by the table size field **1902**. Index source register **2102** specifies a eight offsets used to address the tables. A first index iA addresses Table 1, a second index iB addresses Table 2, a third index iC addresses Table 3, a fourth index iD addresses Table 4, a fifth index iE addresses Table 5, a sixth index iF addresses Table 6, a seventh index iG addresses Table 7, and an eighth index iH addresses Table 8. Table 1 data is stored in memory banks **1** and **2**. Table 2 data is stored in memory banks **3** and **4**. Table 3 data is stored in memory banks **5** and **6**. Table 4 data is stored in memory banks **7** and **8**. Table 5 data is stored in memory banks **9** and **10**. Table 6 data is stored in memory banks **11** and **12**. Table 7 data is stored in memory banks **13** and **14**. Table 8 data is stored in memory banks **15** and **16**.

[0147] FIG. **25** illustrates look up table organization when the corresponding look up table configuration register **1900** specifies sixteen tables for that table set. The look up table set base address register **2101** specifies the beginning of the table set. The number of tables field **1908** specifies sixteen tables. The end of the memory allocated to the table set is specified by the table size field **1902**. Index source register **2102** specifies sixteen offsets used to address the tables. A first index iA addresses Table 1, a second index iB addresses Table 2, a third index iC addresses Table 3, a fourth index iD addresses Table 4, a fifth index iE addresses Table 5, a sixth index iF addresses Table 6, a seventh index iG addresses Table 7, an eighth index iH addresses Table 8, a

ninth index iI addresses Table 9, a tenth index iJ addresses Table 10, an eleventh index iK addresses Table 11, a twelfth index iL addresses Table 12, a thirteenth index iM addresses Table 13, a fourteenth index iN addresses Table 14, a fifteenth index iO addresses Table 15, and a sixteenth index iP addresses Table 16. Table 1 data is stored in memory bank **1**. Table 2 data is stored in memory bank **2**. Table 3 data is stored in memory bank **3**. Table 4 data is stored in memory bank **4**. Table 5 data is stored in memory bank **5**. Table 6 data is stored in memory bank **6**. Table 7 data is stored in memory bank **7**. Table 8 data is stored in memory bank **8**. Table 9 data is stored in memory bank **9**. Table 10 data is stored in memory bank **10**. Table 11 data is stored in memory bank **11**. Table 12 data is stored in memory bank **12**. Table 13 data is stored in memory bank **13**. Table 14 data is stored in memory bank **14**. Table 15 data is stored in memory bank **15**. Table 16 data is stored in memory bank **16**.

[0148] Below is the form of a look up table read (LUTRD) instruction in accordance with one example embodiment. [0149] LUTRD tbl_index, tbl_set, dst

[0150] Tbl_index is an instruction operand specifying a vector register (such as within general vector register file **231**) by register number. This is interpreted as index numbers as shown in Table 11. Tbl_set is a number [0:3] specifying the table set employed in the instruction. This named table set number specifies: a corresponding look up table base address register storing the table base address, which may a scalar register or a vector register; a corresponding look up table configuration register (FIG. **19**), which may a scalar register or a vector register; and the corresponding operative portion of the look up table enable register (FIG. **20**), which may a scalar register or a vector register. The look up table base address register corresponding to the named table set determines the base address of the table set. The indices of the vector register named by Tbl_index are offset from this table set base address. The look up table configuration register corresponding to the named table set determines: the promotion mode (Table 4); the amount of memory allocated to the table size (Table 5); the weight size for histogram operations (Table 6); n-element interpolation for look up table read operations (Table 7); whether values are to be treated as signed or unsigned; whether histogram bin entries are saturated to min/max values; the data element size (Table 8); and the number of tables in the table set (Table 9). Dst is an instruction operand specifying a vector register (such as within general vector register file **231**) by register number as the destination of the table look up operation. The data recalled from the table as specified by these other parameters is packed and stored in this destination register. The process of promotion does not add any performance penalty.

[0151] FIG. **26** illustrates an example of the operation of the look up table read instruction of this invention. In the example illustrated in FIG. **26**, the corresponding look up table configuration register (**1900**) specifies four parallel tables, a data element size of byte (8 bits), and no promotion. To perform look up table operations, the look up table enable register field (in register **2000**) corresponding to the selected table set must enable either read operation (01) or both read and write operations (11).

[0152] The look up table base address register **2101** corresponding to the specified table set stores the base address for the look up table set as illustrated schematically in FIG. **26**. The table data is stored in a portion of level one data cache **123** configured as directly accessible memory, such as disclosed in U.S. Pat. No. 6,606,686 entitled UNIFIED MEMORY SYSTEM ARCHITECTURE INCLUDING CACHE AND DIRECTLY ADDRESSABLE STATIC RANDOM ACCESS MEMORY.

[0153] The example illustrated in FIG. **26** has four tables: table **1 2611**; table **2 2612**; table **3 2613**; and table **4 2614**. As shown in Table 11, this instruction with these selected options treats the data stored in vector source index register **2102** as a set of 4 32-bit fields specifying table offsets. The first field (bits Vx [31:0]) stores iA, the index into the first table **2611**. In this example, this indexes to element A5. The second field (bits Vx[63:32]) stores iB, the index into the second table **2612**. In this example, this indexes to element B1. The third field (bits Vx[95:64]) stores iC, the index into

the third table **2613**. In this example, this indexes to element C8. The fourth field (bits Vx[127:96]) stores iD, the index into the fourth table **2614**. In this example, this indexes to element D10. The various indices are the memory address offsets from the base address for the table set to the specified data element. In accordance with the operation of this look up table read instruction, the indexed data element in table **1 2611** (A5) is stored in a first data slot in destination register **2120**. The indexed data element in table **2 2612** (B1) is stored in a second data slot in destination register **2120**. The indexed data element in table **3 2613** (C8) is stored in a third data slot in destination register **2120**. The indexed data element in table **4 2614** (D10) is stored in a fourth data slot in destination register **2120**. In accordance with this example implementation, other data slots of destination register **2120** are zero filled.

[0154] The look up table read instruction maps the data recalled from the table(s) directly to vector lanes of destination register **2120**. The instruction maps earlier elements to lower lane numbers and later elements to higher lane numbers. The look up table read instruction deposits elements in vectors in increasing-lane order. The look up table read instruction fills each vector lane of destination register **2120** with elements recalled from the table(s). If the recalled data does not equal the vector length, the look up table read instruction pads the excess lanes of destination register **2120** with zeros.

[0155] When a promotion mode is enabled (promotion field **1901** of the corresponding look up table configuration register **1900 #00**), the look up table read instruction promotes each recalled data element to a larger size. FIG. **27** illustrates an example of the operation of the look up table read instruction in accordance with an example embodiment. FIG. **27** illustrates an operation similar to FIG. **26** except that a 2× promotion is enabled (promotion field **1901** is 01). As in FIG. **26**, each of the four indices of vector source index register **2102** recalls a data element from a corresponding table. FIG. **27** illustrates these are placed in destination register **2120** differently than in FIG. **26**. Each recalled data element is stored in a slot in destination register **2120** together with an equally sized extension. This extension is formed corresponding to the signed/unsigned indication of signed field **1906** of the corresponding look up table configuration register. If signed field **1906** indicates unsigned (0), then the extension is zero filled. If signed field **1906** indicates signed (1), then the extension slot is filled with the same value as the most significant bit (sign bit) of the corresponding data element. This treats the data element as a signed integer.

[0156] FIG. **28** illustrates an example of the operation of the look up table read instruction in accordance with an example embodiment. FIG. **28** illustrates an operation similar to FIG. **26** except that a 4× promotion is enabled (promotion field **1901** is 10). Each of four indices of vector source index register **2102** recalls a data element from each table. FIG. **28** illustrates these are placed in destination register **2120** differently than in FIG. **26**. Each recalled data element is stored in a slot in destination register **2120** together with three equally sized extensions. These extensions are formed corresponding to the signed/unsigned indication of signed field **1906** of the corresponding look up table configuration register.

[0157] Those skilled in the art would understand that other data element sizes (e.g., half word, word) would be similarly implemented. Further, other promotion factors, such as a promotion factor of 8×, would be similarly achieved. Those skilled in the art would understand how to apply the principles described in this disclosure to other numbers of look up tables within the selected set of tables.

[0158] FIGS. **29A** and **29B** together illustrate an example embodiment of implementation of promotion. Temporary register **2950** receives table data recalled from level one data cache **123**. Temporary register **2950** includes 16 bytes arranged in 16 1-byte blocks lane **1** to lane **16**. Note that these lanes are each equal in length to the minimum of data size specifiable in element size field **1907**. In this example that is 1 byte/8 bits. Extension elements **2901** to **2908** form the extensions to respective lanes **1** to **8**. A plurality of multiplexers **2932** to **2946** couple input lanes from temporary register **2950** to corresponding lanes of destination register **2120**. Not all input lanes of temporary

register **2950** are coupled to every multiplexer **2932** to **2946**. Many multiplexers **2932** to **2946** also receive an extension input and one or more extension elements **2901** to **2908**. Note there is no multiplexer supplying lane **1** of output register **2120**. Lane **1** of destination register **2120** is always supplied by lane **1** of temporary register **2950** in this illustrated embodiment.

[0159] FIG. **30** illustrates an exemplary extension element N of FIG. **29A**. The sign bit (S) of data element N of temporary register **2950** supplies one input of a corresponding extension multiplexer **3001**. The sign bit of a signed integer is the most significant bit of the value as shown in FIG. **30**. A constant 0 supplies a second input of multiplexer **3001**. Multiplexer **3001** and other similar multiplexers corresponding to other input data elements are controlled by a signed/unsigned signal. This signed/unsigned signal based upon signed field **1906** of the corresponding look up table configuration register **1900**. If signed field **1906** is 0, then multiplexer **3001** (and the corresponding multiplexers for other input lanes) selects the constant 0 input. If signed field **1906** is 1, then multiplexer **3001** (and the corresponding multiplexers for other input lanes) selects the sign bit input. The selected extension is supplied to expansion element **3002**. Expansion element **3002** expands the bit selected by multiplexer **3001** to the lane size. In accordance with this example, the lane size is selected to equal the minimum table data element size of 1 byte. For a specified table data size equal to the lane size and in which the signed field **1906** is 0, the next data slot is filled with 0's effecting a zero extension. If signed field **1906** is 1, the next data slot is filled with the sign bit of the data element effecting a sign extension. Multiplexers **2932** to **2946** select the proper extension corresponding to the specified table data element size. If the selected table data element size is half word, multiplexers **2932** to **2946** are controlled to select the extension from alternating extension elements. If the selected table data element size is word, multiplexers **2932** to **2946** are controlled to select the extension from every fourth extension element.

[0160] Multiplexers **2932** to **2946** are controlled by multiplexer control encoder **3110** illustrated in FIG. **31**. Multiplexer control encoder **3110** receives an element data size input (element size field **1907**), a promote indication (promotion field **1901**) and generates corresponding control signals for multiplexers **2932** to **2946**. Not all input bytes can supply each output byte. Table 12 illustrates this control. Table 12 shows the source data for each of the 16 lanes of destination register **2120** for the various data sizes and promotion modes in accordance with an example embodiment.

TABLE-US-00012

TABLE	12	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	--1x	16	15	14	13	12	11	10	9	8																																																																																
7	6	5	4	3	2	1	b-2x	e8	8	e7	7	e6	6	e5	5	e4	4	e3	3	e2	2	e1	1	b-4x	e4	e4	e4	4	e3	e3	e3	3	e2	e2	e2	2	e1	e1	e1	1	b-8x	e2	e2	e2	e2	e2	e2	e2	2	e1	e1	e1	e1	e1	e1	e1	1	hw-2x	e8	e8	8	7	e6	e6	6	5	e4	e4	4	3	e2	e2	2	1	hw-4x	e4	e4	e4	e4	e4	e4	4	3	e2	e2	e2	e2	e2	2	1	w-2x	e8	e8	e8	e8	8	7	6	5	e4	e4	e4	e4	4	3	2	1

[0161] Note that lane **1** of destination register **2120** is always the same as lane **1** of temporary register **2950** regardless of selected data size or promotion factor. The column devoted to lane **1** includes all 1's and FIG. **29A** illustrates a straight connection between lane **1** of temporary register **2950** and destination register **2120**. The first row of Table 12 shows that for no promotion (1x), each lane of destination register **2120** is the same as temporary register **2950** regardless of the selected table data element data size. For a data size of byte and a promotion factor of 2 (b-2x), multiplexer **2932** selects the extension of lane **1** (e1), multiplexer **2933** selects the data of input lane **2**, multiplexer **2934** selects the extension of lane **2** (e2), multiplexer **2935** selects the data of input lane **3**, multiplexer **2936** selects the extension of lane **3** (e3), etc. For a data size of byte and a promotion factor of 4 (b-4x), multiplexers **2932** to **2934** select the extension of lane **1** (e1), multiplexer **2935** selects the data of input lane **2** and multiplexers **2936** to **2938** select the extension of lane **2** (e2), multiplexer **2939** selects the data of input lane **3**, multiplexers **2940** to **2942** select the extension of lane **3** (e3), etc. For a data size of byte and a promotion factor of 8 (b-8x), multiplexers **2932** to **2938** select the extension of lane **1** (e1), multiplexer **2939** selects the data of input lane **2**, and multiplexers **2940** to **2946** select the extension of lane **2** (e2). For a data size of half word and a promotion factor of 2 (hw-2x), multiplexer **2932** selects the data of lane **2**,

multiplexers **2933** and **2934** select the extension of lane **2** (e2), multiplexer **2935** selects the data of lane **3**, multiplexer **2936** selects the data of lane **4**, multiplexers **2937** and **2938** select the extension of lane **4** (e4), etc. For a data size of half word and a promotion factor of 4 (hw-4x), multiplexer **2932** selects the data of lane **2**, multiplexers **2933** to **2938** select the extension of lane **2** (e2), multiplexer **2939** selects the data of lane **3**, multiplexer **2940** selects the data of lane **4**, and multiplexers **2941** and **2946** select the extension of lane **4** (e4). For a data size of word and a promotion factor of 2 (w-2x), multiplexer **2932** selects data of lane **2**, multiplexer **2933** selects data of lane **3**, multiplexer **2934** selects data of lane **4**, multiplexers **2935** to **2938** select the extension of lane **4** (e4), multiplexer **2939** selects the data of lane **5**, multiplexer **2940** selects the data of lane **6**, multiplexer **2941** selects the data of lane **7**, multiplexer **2942** selects the data of lane **8** and multiplexers **2943** to **2946** select the extension of lane **8**. As previously described, these are all the combinations of data size and promotion factor supported in the present example.

[0162] FIG. **32** illustrates another example of the operation of the look up table read instruction of this disclosure. In the example illustrated in FIG. **32**, the corresponding look up table configuration register (**1900**) specifies four parallel tables, a data element size of word (32 bits), and 2-element interpolation. To perform look up table operations, the look up table enable register field (in register **2000**) corresponding to the selected table set must enable either read operation (01) or both read and write operations (11).

[0163] As above, the look up table base address register **2101** corresponding to the specified table set stores the base address for the look up table set as illustrated schematically in FIG. **32**. The table data is stored in a portion of level one data cache **123** configured as directly accessible memory.

[0164] The example illustrated in FIG. **32** has four tables: table **1 2611**; table **2 2612**; table **3 2613**; and table **4 2614**. As shown in Table 11, this instruction with these selected options treats the data stored in vector source index register **2102** as a set of 4 32-bit fields specifying table offsets. The first field (bits Vx[31:0]) stores iA, the index into the first table **2611**. In this example, this indexes to element A5. The second field (bits Vx[63:32]) stores iB, the index into the second table **2612**. In this example, this indexes to element B1. The third field (bits Vx[95:64]) stores iC, the index into the third table **2613**. In this example, this indexes to element C8. The fourth field (bits Vx[127:96]) stores iD, the index into the fourth table **2614**. In this example, this indexes to element D10. The various indices are the memory address offsets from the base address for the table set to the specified data element.

[0165] When an interpolation mode is enabled (interpolation field **1904** of the corresponding look up table configuration register **1900**≠00), the look up table read instruction returns one or more additional data elements than the indexed element per table. FIG. **32** illustrates an example of the operation of the look up table read instruction in accordance with an example embodiment. FIG. **32** illustrates an operation similar to FIG. **26**, described above, except that a 2-element interpolation is enabled (interpolation field **1904** is 001). As in FIG. **26**, each of the four indices of vector source index register **2102** recalls a data element from a corresponding table. FIG. **32** illustrates these are placed in destination register **2120** differently than in FIG. **26**. In particular, 2 data elements are returned for each of the four indices: the data element recalled by a particular index and the next adjacent data element (regardless of row boundaries). For example, if the data element recalled by a particular index is A0, then the next adjacent data element is A1; if the data element recalled by a particular index is A7, then the next adjacent data element is A8 although A8 is on a different row.

[0166] Each recalled data element is stored in a slot in destination register **2120**. In accordance with the operation of this look up table read instruction where 2-element interpolation is enabled, the indexed data element in table **1 2611** (A5) and its next adjacent data element (A6) are stored in first and second data slots in destination register **2120**. The indexed data element in table **2 2612** (B1) and its next adjacent data element (B2) are stored in third and fourth data slots in destination register **2120**. The indexed data element in table **3 2613** (C8) and its next adjacent data element (C9) are stored in fifth and sixth data slots in destination register **2120**. The indexed data element in

table **4 2614** (D10) and its next adjacent data element (D11) are stored in a seventh and eighth data slots in destination register **2120**. In accordance with this example implementation, other data slots of destination register **2120** are zero filled.

[0167] FIG. **33** illustrates an example of the operation of the look up table read instruction in accordance with an example embodiment. FIG. **33** illustrates an operation similar to FIG. **32** except that a 4-element interpolation is enabled (interpolation field **1904** is 010). As in FIG. **32**, each of four indices of vector source index register **2102** recalls a data element from each table. FIG. **33** illustrates these are placed in destination register **2120** differently than in FIG. **32**. In particular, 4 data elements are returned for each of the four indices: the data element recalled by a particular index and the next 3 adjacent data elements (regardless of row boundaries). For example, if the data element recalled by a particular index is A0, then the next 3 adjacent data elements are A1-A3; if the data element recalled by a particular index is A7, then the next 3 adjacent data elements are A8-A10, although A8-A10 are on a different row.

[0168] Each recalled data element is stored in a slot in destination register **2120**. In accordance with the operation of this look up table read instruction where 4-element interpolation is enabled, the indexed data element in table **1 2611** (A5) and its next 3 adjacent data elements (A6-A8) are stored in the first 4 data slots in destination register **2120**. The indexed data element in table **2 2612** (B1) and its next 3 adjacent data elements (B2-B4) are stored in the second 4 data slots in destination register **2120**. The indexed data element in table **3 2613** (C8) and its next 3 adjacent data elements (C9-C11) are stored in the third 4 data slots in destination register **2120**. The indexed data element in table **4 2614** (D10) and its next 3 adjacent data elements (D11-D13) are stored in the fourth 4 data slots in destination register **2120**. In this example, where the data element size is word, the 16 recalled data elements completely fill the destination register **2120**; however, in an otherwise-similar example where the data element size is instead half-word or byte, the 16 recalled data elements would not completely fill the destination register **2120** and the remainder of data slots of destination register **2120** are zero filled.

[0169] Those skilled in the art would understand how to apply the principles described in this disclosure to other numbers of look up tables within the selected set of tables. For example, 8-element interpolation is not possible when the number of tables is 4 and the tables are arranged in level one data cache **123** in the manner shown in FIG. **33**, since only one element per memory bank is accessible at a time. However, 8-element interpolation is possible when the number of tables is 2 or 1.

[0170] FIG. **34** illustrates an example embodiment of implementation of interpolation, discussed above. In the example of FIG. **34**, an intermediate register **3402** receives table data recalled from level one data cache **123**. In this example, the level one data cache **123** that contains the tables **2611**, **2612**, **2613**, **2614** is configured to provide a word of data from each of its 16 banks (described above) regardless of the data requested by a look up read instruction. The data provided to the intermediate register **3402** is ordered as it appears in the 16 banks of the level one data cache **123**, regardless of interpolation or other variables specified by the look up table configuration register **1900**.

[0171] Continuing the example of FIG. **33**, in which the look up table read instruction includes 4-element interpolation, the intermediate register **3402** contains each of the four indexed data elements (e.g., A5, B1, C8, D10) and the next 3 adjacent data elements from each of the indexed data elements. However, as explained above, the intermediate register **3402** contains these data elements ordered as they appear in the 16 banks of the level one data cache **123**, and thus not necessarily in numerical order of the data elements as shown in the destination register **2120** in FIG. **33** above.

[0172] For example, the four elements from Table **1 2611** (A5-A8) appear in the order A8, A5, A6, A7, since this is the order in which those elements appear in the first four banks of the level one data cache **123**. On the other hand, the four elements from Table **3 2613** (C8-C11) appear in order

in the intermediate register **3402** since the element C8 is already in the lowest bank of the level one data cache **123** corresponding to Table 3 **2613**.

[0173] In order to facilitate proper ordering of data elements written to the destination register **2120**, explained above with respect to FIG. **33**, examples of this disclosure include a multi-stage butterfly unit **3404**, which receives the intermediate register **3402** as an input and produces an output that is written to the destination register **2120**. The butterfly unit **3404** is configured to reorder the bits of the intermediate register **3402** according to various control signals. These control signals include, but are not necessarily limited to, all or a portion of the addresses that correspond to the indexed data elements in each of the tables **2611**, **2612**, **2613**, **2614**. For example, decoding the indices **3401** (or portions of the addresses of the indexed data elements) indicates the position of an indexed data element within a table and thus whether reordering may be necessary. In the present example, an address of the indexed data element A5 indicates A5 is not aligned with the lowest bank of the level one data cache **123** corresponding to Table 1 **2611**, and thus the bits of the intermediate register **3402** corresponding to Table 1 **2611** should be reordered. On the other hand, an address of the indexed data element C8 indicates C8 is aligned with the lowest bank of the level one data cache **123** corresponding to Table 3 **2613**, and thus the bits of the intermediate register **3402** corresponding to Table 3 **2613** need not be reordered.

[0174] To further facilitate proper ordering of data elements written to the destination register **2120**, the multi-stage butterfly unit **3404** also receives all or portions of the look up table configuration register **1900** as control signal(s). In particular, the interpolation field **1904**, the element size field **1907**, and the number of tables field **1908** may influence the function of the multi-stage butterfly unit **3404**. While FIG. **34** is meant to illustrate how the butterfly unit **3404** processes a set of data elements from the look up tables **2611**, **2612**, **2613**, **2614** in accordance with the example shown in in FIG. **34**, the butterfly unit **3404** can process the data elements in accordance with a number of different possible settings in the look up table configuration register **1900**. Additional examples of the butterfly unit **3404** functionality are provided below.

[0175] In a first example, the control signals from the look up table configuration register **1900** provided to the multi-stage butterfly network **3404** include the element size field **1907** indicating a size of word, the interpolation field **1904** indicating no interpolation, and the number of tables field **1908** indicating two tables. In this example, the multi-stage butterfly network **3404** receives one indexed element from each group of banks **1-8** and banks **9-16** of the level one data cache **123**, for example according to the two-table embodiment shown in FIG. **22**. Thus, in response to these control signals from the look up table configuration register **1900**, the multi-stage butterfly network **3404** places the indexed elements from each group of banks **1-8** and banks **9-16** in the first two word-size lanes of the destination register **2120**, respectively. In one example, the remaining lanes of the destination register **2120** are zero-filled, while in other examples the remaining lanes of the destination register may be filled in different manners.

[0176] In a second example, the control signals from the look up table configuration register **1900** provided to the multi-stage butterfly network **3404** include the element size field **1907** indicating a size of word, the interpolation field **1904** indicating 2-element interpolation, and the number of tables field **1908** indicating two tables. In this example, the multi-stage butterfly network **3404** receives one indexed element and a next adjacent element (e.g., according to 2-element interpolation, explained above) from each group of banks **1-8** and banks **9-16** of the level one data cache **123**. Thus, in response to these control signals from the look up table configuration register **1900**, the multi-stage butterfly network **3404** places the indexed element and the next adjacent element from the group of banks **1-8** in order in the first two word-size lanes of the destination register **2120**. Similarly, the multi-stage butterfly network **3404** places the indexed element and the next adjacent element from the group of banks **9-16** in order in the second two word-size lanes of the destination register **2120**. In one example, the remaining lanes of the destination register **2120** are zero-filled, while in other examples the remaining lanes of the destination register may be filled

in different manners.

[0177] In a third example, the control signals from the look up table configuration register **1900** provided to the multi-stage butterfly network **3404** include the element size field **1907** indicating a size of word, the interpolation field **1904** indicating 8-element interpolation, and the number of tables field **1908** indicating two tables. In this example, the multi-stage butterfly network **3404** receives one indexed element and a next 7 adjacent elements (e.g., according to 8-element interpolation) from each group of banks **1-8** and banks **9-16** of the level one data cache **123**. As explained above, the next 7 adjacent elements may wrap into a subsequent row. Thus, in response to these control signals from the look up table configuration register **1900**, the multi-stage butterfly network **3404** places the indexed element and the next 7 adjacent elements from the group of banks **1-8** in order in the first eight word-size lanes of the destination register **2120**. Similarly, the multi-stage butterfly network **3404** places the indexed element and the next 7 adjacent elements from the group of banks **9-16** in order in the second eight word-size lanes of the destination register **2120**. In this example, assuming a 512-bit destination register **2120**, all lanes are filled by the read operation and thus no additional filling is required.

[0178] Extensions of the above-described functionality of the multi-stage butterfly network **3404** in response to different combinations of control signals from the look up table configuration register **1900** should be apparent to one of ordinary skill in the art. For example, changes to the number of tables field **1908** affects the “boundaries” on which elements may be reordered before writing to the destination register **2120** (e.g., the number of tables field **1908** indicating four tables results in “boundaries” between groups of banks **1-4**, **5-8**, **9-12**, and **13-16**, while the number of tables field **1908** indicating eight tables results in “boundaries” between groups of banks **1-2**, **3-4**, **5-6**, **7-8**, **9-10**, **11-12**, **13-14**, and **15-16**). As another example, changes to the element size field **1907** affect how bits from the intermediate register **3402** are packed into the destination register **2120**.

[0179] Below is the form of a look up table write (LUTWR) instruction in accordance with one example embodiment. [0180] LUTWR tbl_index, tbl_set, write_data

[0181] Tbl_index is an instruction operand specifying a vector register (such as within general vector register file **231**) by register number. This is interpreted as index numbers as shown in Table 11, above. Tbl_set is a number [0:3] specifying the table set employed in the instruction. This named table set number specifies: a corresponding look up table base address register storing the table base address, which may be a scalar register or a vector register; a corresponding look up table configuration register (FIG. **19**), which may a scalar register or a vector register; and the corresponding operative portion of the look up table enable register (FIG. **20**), which may a scalar register or a vector register. The look up table base address register corresponding to the named table set determines the base address of the table set. The indices of the vector register named by Tbl_index are offset from this table set base address. The look up table configuration register corresponding to the named table set determines: the promotion mode (Table 4); the amount of memory allocated to the table size (Table 5); the weight size for histogram operations (Table 6); n-element interpolation for look up table read operations (Table 7); whether values are to be treated as signed or unsigned; whether histogram bin entries are saturated to min/max values; the data element size (Table 8); and the number of tables in the table set (Table 9). Write_data is an instruction operand, specifically a source operand, specifying a vector register (such as within general vector register file **231**) by register number to provide source data to be written to the look up tables. As above, the number of tables, size of the elements, and other parameters are specified in the look up table configuration register **1900**.

[0182] FIG. **35** illustrates an example of the operation of the look up table write instruction of this disclosure. In the example illustrated in FIG. **35**, the corresponding look up table configuration register (**1900**) specifies four parallel tables and a data element size of word (32 bits). To perform look up table operations, the look up table enable register field (in register **2000**) corresponding to the selected table set must enable both read and write operations (11).

[0183] As above, the look up table base address register **2101** corresponding to the specified table set stores the base address for the look up table set as illustrated schematically in FIG. **35**. The table data is stored in a portion of level one data cache **123** configured as directly accessible memory.

[0184] The example illustrated in FIG. **35** has four tables: table **1 2611**; table **2 2612**; table **3 2613**; and table **4 2614**. As shown in Table 11, this instruction with these selected options treats the data stored in vector source index register **2102** as a set of 4 32-bit fields specifying table offsets. The first field (bits Vx[31:0]) stores iA, the index into the first table **2611**. In this example, this indexes to element A5 (e.g., between A4 and A6). The second field (bits Vx[63:32]) stores iB, the index into the second table **2612**. In this example, this indexes to element B1 (e.g., between B0 and B2). The third field (bits Vx[95:64]) stores iC, the index into the third table **2613**. In this example, this indexes to element C8 (e.g., between C7 and C9). The fourth field (bits Vx[127:96]) stores iD, the index into the fourth table **2614**. In this example, this indexes to element D10 (e.g., between D9 and D11). The various indices are the memory address offsets from the base address for the table set to the specified data element to be written.

[0185] A vector source data register **3502** contains data to be written to the indexed data elements of the look up tables **2611, 2612, 2613, 2614**. In this example, because the look up table configuration register specifies a number of tables of four and an element size of word, the first four words of the vector source data register **3502** are utilized by the look up table write instruction, while the remainder of the vector source data register **3502** is not utilized by the look up table write instruction. In particular, the first word (W1) is written to the element specified by the index iA, or A5; the second word (W2) is written to the element specified by the index iB, or B1; the third word (W3) is written to the element specified by the index iC, or C8; and the fourth word (W4) is written to the element specified by the index iD, or D10.

[0186] Extensions of the above-described look up table write instruction in response to different parameters specified by the look up table configuration register **1900** should be apparent to one of ordinary skill in the art. For example, changes to the number of tables field **1908** affects the number of indexes specified by the vector source index register **2102** (e.g., as shown in FIGS. **21-25**). Similarly, changes to the element size field **1907** affects the portion of the vector source data register **3502** that provides source data to be written to the indexed data elements of the look up tables.

[0187] Below is the form of a look up table initialization (LUTINIT) instruction in accordance with one example embodiment. [0188] LUTINIT tbl_index, tbl_set, write_data

[0189] Tbl_index, tbl_set, and write_data are generally similar to those described above with respect to the look up table write instruction. As above, the number of tables, size of the elements, and other parameters are specified in the look up table configuration register **1900**. Unlike the look up table write instruction, which writes source data only to an indexed element in each table (tables **2611, 2612, 2613, 2614** in the example of FIG. **35**), the look up table initialization instruction duplicates source data to more efficiently write to larger portions of the look up tables. As suggested by the instruction name, such duplication of source data is particularly useful when initializing elements of look up tables to particular values.

[0190] The look up table initialization instruction specifies source data for a single table (e.g., the vector source index register **2102** contains only a single index, for example in the first field (bits Vx[31:0])). The source data specified by the vector source data register **3502** varies in size depending on the number of tables specified by the look up table configuration register **1900**. In response to execution of a look up table initialization instruction, the level one data cache **123** replicates the source data internally, based on the number of tables specified by the look up table configuration register **1900**, and writes the resulting replicated data to the location specified by the index value in the vector source index register **2102** and the look up table base address register **2101**. The duplicated data is written to the location specified by the index value in the vector source index register **2102** along with corresponding locations in each of the other tables in the table set.

[0191] FIGS. 36A and 36B show examples of the initialization of the level one data cache **123** resulting from execution of exemplary look up table initialization instructions. In the example of FIG. 36A, the number of tables is 16 and the element size is word. The following are the exemplary look up table initialization instructions, the execution of which results in the example population **3604** of the level one data cache **123**: [0192] LUTINIT D0, 0, B0; where D0=0x00 (e.g., the index of the element in row 0, level one data cache **123** bank **0**), 0 is the specified table set, B0=D[63:0] [0193] LUTINIT D1, 0, B1; where D1=0x02 (e.g., the index of the element in row 1, level one data cache **123** bank **0**), 0 is the specified table set, B1=D[127:64] [0194] LUTINIT D2, 0, B2; where D2=0x04 (e.g., the index of the element in row 2, level one data cache **123** bank **0**), 0 is the specified table set, B2=D[191:128] [0195] LUTINIT D3, 0, B3; where D3=0x06 (e.g., the index of the element in row 3, level one data cache **123** bank **0**), 0 is the specified table set, B3=D[255:192] [0196] As explained above, the source data specified by the vector source data register **3502** varies in size depending on the number of tables specified by the look up table configuration register **1900**. In this example, the level one data cache has a width of 1024 bits and there are 16 tables, and thus each table is 64 bits wide. The registers B0-B3 are scalar registers, also having a size of 64 bits, and thus the entire contents of the registers B0-B3 are utilized by the look up table initialization instructions. In another example, the source data register is the vector source data register **3502**, and thus only a portion of the contents of the register (e.g., the first 64 bits) is utilized by the lookup table initialization instruction.

[0197] The first look up table initialization instruction results in 64 bits of source data from register B0 being written to each of the 16 tables in the table set 0, beginning at the location specified by the index 0x00 (plus a base address from the look up table configuration register **1900**), which is the first element in row 0. The second look up table initialization instruction results in 64 bits of source data from register B1 being written to each of the 16 tables in the table set 0, beginning at the location specified by the index 0x02 (plus the base address from the look up table configuration register **1900**), which is the first element in row 1. The third look up table initialization instruction results in 64 bits of source data from register B2 being written to each of the 16 tables in the table set 0, beginning at the location specified by the index 0x04 (plus the base address from the look up table configuration register **1900**), which is the first element in row 2. The fourth look up table initialization instruction results in 64 bits of source data from register B3 being written to each of the 16 tables in the table set 0, beginning at the location specified by the index 0x06 (plus the base address from the look up table configuration register **1900**), which is the first element in row 3.

[0198] As will be explained further below, in the example of FIG. 36A, since there are 16 tables and the element size is word, there are two words per row per table. The permitted index values (e.g., in registers D0-D3) correspond to the first element of each row, and thus also increase by two (e.g., 0x00, 0x02, 0x04, 0x06, and so on). If the element size was, instead, half word, there would be four half words per row per table, and the permitted index values would increase by four (e.g., 0x00, 0x04, 0x08, 0x0C, and so on). Similarly, if the element size was, instead, byte, there would be eight bytes per row per table, and the permitted index values would increase by eight (e.g., 0x00, 0x08, 0x10, 0x18, and so on). This convention is reflected in the following Table 13, which provides an example of row addressing for each supported number of tables (“ways” in Table 13) and element size configuration. Such row addressing may be employed by successive look up table initialization instructions to populate an entire look up table, with subsequent initialization instructions specifying the index of the first element in the row that is being populated.

TABLE-US-00013 TABLE 13 No of Ways Element type Index for LUTINT 16 word 0 × 0, 0 × 2, 0 × 4, 0 × 6, 0 × 8, 0 × A, 0 × C, 0 × E, . . . halfword 0 × 0, 0 × 4, 0 × 8, 0 × C, 0 × 10, 0 × 14, 0 × 18, 0 × 1C, . . . byte 0 × 0, 0 × 8, 0 × 10, 0 × 18, 0 × 20, 0 × 28, 0 × 30, 0 × 38, 0 × 40, . . . 8 word 0 × 0, 0 × 4, 0 × 8, 0 × C, 0 × 10, 0 × 14, 0 × 18, 0 × 1C, . . . halfword 0 × 0, 0 × 8, 0 × 10, 0 × 18, 0 × 20, 0 × 28, 0 × 30, 0 × 38, 0 × 40, . . . byte 0 × 0, 0 × 10, 0 × 20, 0 × 30, 0 × 40, 0 × 50, 0 × 60, 0 × 70, 0 × 80, . . . 4 word 0 × 0, 0 × 8, 0 × 10, 0 × 18, 0 × 20, 0 × 28, 0 × 30, 0 × 38, 0 × 40, . . .

halfword $0 \times 0, 0 \times 10, 0 \times 20, 0 \times 30, 0 \times 40, 0 \times 50, 0 \times 60, 0 \times 70, 0 \times 80, \dots$ byte $0 \times 0, 0 \times 20, 0 \times 40, 0 \times 60, 0 \times 80, 0 \times 0, 0 \times C0, 0 \times E0, 0 \times 100, \dots$ 2 word $0 \times 0, 0 \times 10, 0 \times 20, 0 \times 30, 0 \times 40, 0 \times 50, 0 \times 60, 0 \times 70, 0 \times 80, \dots$ halfword $0 \times 0, 0 \times 20, 0 \times 40, 0 \times 60, 0 \times 80, 0 \times 0, 0 \times C0, 0 \times E0, 0 \times 100, \dots$ byte $0 \times 0, 0 \times 40, 0 \times 80, 0 \times C0, 0 \times 100, 0 \times 140, 0 \times 180, 0 \times 1C0, 0 \times 200, 0 \times 240, \dots$ 1 word $0 \times 0, 0 \times 10, 0 \times 20, 0 \times 30, 0 \times 40, 0 \times 50, 0 \times 60, 0 \times 70, 0 \times 80, \dots$ halfword $0 \times 0, 0 \times 20, 0 \times 40, 0 \times 60, 0 \times 80, 0 \times 0, 0 \times C0, 0 \times E0, 0 \times 100, \dots$ byte $0 \times 0, 0 \times 40, 0 \times 80, 0 \times C0, 0 \times 100, 0 \times 140, 0 \times 180, 0 \times 1C0, 0 \times 200, 0 \times 240, \dots$

[0199] In the example of FIG. 36B, the number of tables is 1 and the element size is byte.

[0200] The following are the exemplary look up table initialization instructions, the execution of which results in the example population **3608** of the level one data cache **123**: [0201] LUTINIT D0, 0, VB0; where D0=0x00 (e.g., the index of the element in row 0, level one data cache **123** bank **0**), 0 is the specified table set, VB3=DATA0[511:0] [0202] LUTINIT D1, 0, VB1; where D1=0x40 (e.g., the index of the element in row 0, level one data cache **123** bank **8**), 0 is the specified table set, VB1=DATA1[511:0] [0203] LUTINIT D2, 0, VB2; where D2=0x80 (e.g., the index of the element in row 1, level one data cache **123** bank **0**), 0 is the specified table set, VB2=DATA2[511:0] [0204] LUTINIT D3, 0, VB3; where D3=0xC0 (e.g., the index of the element in row 1, level one data cache **123** bank **8**), 0 is the specified table set, VB3=DATA3[511:0] As explained above, the source data specified by the vector source data register **3502** varies in size depending on the number of tables specified by the look up table configuration register **1900**. In this example, the level one data cache **123** has a width of 1024 bits and there is one table, which has a maximum width of one vector, or 512 bits, and thus each row of the level one data cache **123** contains two rows of the table. Since there is only one table, no duplication occurs. The registers VB0-VB3 are vector registers, also having a size of 512 bits, and thus the entire contents of the registers VB0-VB3 are utilized by the look up table initialization instructions.

[0205] The first look up table initialization instruction results in 512 bits of source data from register VB0 being written to the table in the table set 0, at the location specified by the index 0x00 (plus a base address from the look up table configuration register **1900**), which is the first element in row 0. The second look up table initialization instruction results in 512 bits of source data from register VB1 being written to the table in the table set 0, at the location specified by the index 0x40 (plus the base address from the look up table configuration register **1900**), which is the 65th element in row 0 (e.g., the first element in bank **8**). The third look up table initialization instruction results in 512 bits of source data from register VB2 being written to the table in the table set 0, at the location specified by the index 0x80 (plus the base address from the look up table configuration register **1900**), which is the first element in row 1. The fourth look up table initialization instruction results in 512 bits of source data from register VB3 being written to the table in the table set 0, at the location specified by the index 0xC0 (plus the base address from the look up table configuration register **1900**), which is the 65th element in row 1 (e.g., the first element in bank **8**).

[0206] As explained, the level one data cache **123** has a bandwidth of 1024 bits, although the data bus (e.g., 144) between the central processing unit core **110** and the level one data cache **123** is only 512 bits in the example embodiment shown in FIG. 1. Thus, 512 bits is the maximum size of write_data able to be provided to the level one data cache **123** (e.g., from vector source data register **3502**). Duplication is not supported in the example where the number of tables is 1, since there is not another table into which to write duplicated source data. In an example, the look up table initialization instruction when the number of tables is 1 provides the same bandwidth as a look up table write instruction (or a vector store), described above. However, for number of tables equal to 2, 4, 8, or 16, the write_data from the vector source data register **3502** is duplicated according to the following Table 14.

TABLE-US-00014 TABLE 14 No of Element Data Send Data Written to Expansion Ways type Out (bits) L1D SRAM (bits) Factor 16 word 64 1024 16 halfword 64 1024 16 byte 64 1024 16 8 word

128 1024 8 halfword 128 1024 8 byte 128 1024 8 4 word 256 1024 4 halfword 256 1024 4 byte
256 1024 4 2 word 512 1024 2 halfword 512 1024 2 byte 512 1024 2 1 word 512 512 1 halfword
512 512 1 byte 512 512 1

[0207] As demonstrated, depending on the number of tables specified by the look up table configuration register **1900**, the portion of the vector source data register **3502** that is sent to the level one data cache **123** to be duplicated varies, for example from 64 bits when the number of tables is 16 to 512 bits when the number of tables is 2 (duplication allowed) or 1 (duplication not allowed). Further, as explained with respect to FIG. **36A**, in the example where there are 16 tables, resulting in a table width of 64 bits, a scalar register may also contain the source data to be written to the tables. However, in other examples a scalar register cannot be used as the source register since more than 64 bits are needed (e.g., for 8-, 4-, 2-, and 1-table examples).

[0208] Below is the form of a histogram (HIST) instruction and a weighted histogram (WHIST) instruction in accordance with one example embodiment.

TABLE-US-00015 HIST hist_index, hist_set WHIST hist_index, hist_set, hist_weights

[0209] Hist_index is an instruction operand specifying a vector register (such as within general vector register file **231**) by register number. This is interpreted as index numbers as shown in Table 11, above. Hist_index is similar to Tbl_index discussed above, but particularly for the histogram context rather than the look up table context. Similarly, Hist_set is a number [0:3] specifying the histogram set employed in the instruction. This named histogram set number specifies: a corresponding look up table (or histogram) base address register storing the base address of the set of histograms, which may be a scalar register or a vector register; a corresponding look up table (or histogram) configuration register (FIG. **19**), which may be a scalar register or a vector register; and the corresponding operative portion of the look up table (or histogram) enable register (FIG. **20**), which may be a scalar register or a vector register. The base address register corresponding to the named histogram set determines the base address of the histogram set. The indices of the vector register named by Hist_index are offset from this table set base address. The look up table configuration register corresponding to the named table set determines: the promotion mode (Table 4); the amount of memory allocated to the table size (Table 5); the weight size for histogram operations (Table 6); n-element interpolation for look up table read operations (Table 7); whether values are to be treated as signed or unsigned; whether histogram bin entries are saturated to min/max values; the data element size (Table 8); and the number of histograms in the histogram set (Table 9). For weighted histogram (WHIST) instructions, hist_weights is an instruction operand specifying a vector register (such as within general vector register file **231**) by register number to provide weights to increment addressed bin entries in the histograms. Similar to above, the number of histograms, size of the bin entries, size of weights, whether saturation is employed, and other parameters are specified in the configuration register **1900**.

[0210] FIG. **37** illustrates an example of the operation of the histogram instruction of this disclosure. In the example illustrated in FIG. **37**, the corresponding configuration register (**1900**) specifies four parallel histograms **3711**, **3712**, **3713**, **3714** and a data element size of word (32 bits). To perform histogram operations, the enable register field (in register **2000**) corresponding to the selected histogram set should enable both read and write operations (11).

[0211] As above, the base address register **2101** corresponding to the specified histogram set stores the base address for the histogram set as illustrated schematically in FIG. **37**. The histogram data is stored in a portion of level one data cache **123** configured as directly accessible memory.

[0212] The example illustrated in FIG. **37** has four histograms: hist 1 **3711**; hist 2 **3712**; hist 3 **3713**; and hist 4 **3714**. As shown in Table 11, this instruction with these selected options treats the data stored in vector source index register **2102** as a set of 4 32-bit fields specifying table offsets. The first field (bits Vx[31:0]) stores iA, the index into the first histogram **3711**. In this example, this indexes to element A5 (e.g., between A4 and A6). The second field (bits Vx[63:32]) stores iB, the index into the second histogram **3712**. In this example, this indexes to element B1 (e.g.,

between B0 and B2). The third field (bits Vx[95:64]) stores iC, the index into the third histogram **3713**. In this example, this indexes to element C8 (e.g., between C7 and C9). The fourth field (bits Vx[127:96]) stores iD, the index into the fourth histogram **3714**. In this example, this indexes to element D10 (e.g., between D9 and D11). The various indices are the memory address offsets from the base address for the histogram set to the specified bin element to be modified.

[0213] In response to execution of a histogram instruction according to the example of FIG. **37**, the indexed bin entries specified by the base address register **2101** and the vector source index register **2102** are incremented by a value of 1. The bin entry specified by iA (e.g., A5) is incremented by 1; the bin entry specified by iB (e.g., B1) is incremented by 1; the bin entry specified by iC (e.g., C8) is incremented by 1; and the bin entry specified by iD (e.g., D10) is incremented by 1.

[0214] If the saturation field **1905** of the configuration register **1900** is set, then bin entries are saturated (e.g., limited) to min/max values of the element data type in response to the histogram operation. For example, unsigned bytes saturate to [0, 0xFF]; signed bytes saturate to [0x80, 0x7F]; unsigned half-words saturate to [0, 0xFFFF]; signed half-words saturate to [0x8000, 0x7FFF]; unsigned words saturate to [0, 0xFFFF FFFF]; and signed words saturate to [0x8000 0000, 0x7FFF FFFF]. If the saturation field **1905** is 0, then histogram bin entries do not saturate to min/max values of the element data type and instead will wrap around when incremented beyond a maximum value or decremented beyond a minimum value.

[0215] FIG. **38** illustrates an example of the operation of the weighted histogram instruction of this disclosure. FIG. **38** is similar to FIG. **37**, but includes the vector source data register **3502**, explained above. The vector source data register **3502** is specified by hist_weights and includes weights to increment addressed bin entries in the histograms **3711**, **3712**, **3713**, **3714**.

[0216] Unlike above with respect to the look up table write instruction, for weighted histogram instructions, the vector source data register **3502** contains data to be added to the indexed bin entries in the histograms **3711**, **3712**, **3713**, **3714**. In some examples, histogram weights are signed values and weight size is limited to byte and half-word. Further, in some examples, weight size cannot be larger than the specified bin entry size. Thus, for byte-size bins, only byte-size weights are permitted; for half-word or word-size bins, byte or half-word size weights are permitted. In certain examples, for word-size bins, word size weights are permitted as well. In this example, because the look up table configuration register specifies a number of histograms of four and a weight size of half-word (which is permitted due to the bin entry size being specified as word-size), the first four half-words of the vector source data register **3502** are utilized by the weighted histogram instruction, while the remainder of the vector source data register **3502** is not utilized by the weighted histogram instruction. In particular, the first half-word (value of +5) is added to the bin entry specified by the index iA (e.g., A5 is incremented by 5); the second half-word (value of +2) is added to the bin entry specified by the index iB (e.g., B1 is incremented by 2); the third half-word (value of -3) is added to the bin entry specified by the index iC (e.g., C8 is decremented by 3); and the fourth half-word (value of +7) is added to the bin entry specified by the index iD (e.g., D10 is incremented by 7).

[0217] Similar to the above histogram instruction, if the saturation field **1905** of the configuration register **1900** is set, then bin entries are saturated (e.g., limited) to min/max values of the element data type in response to the histogram operation. For example, unsigned bytes saturate to [0, 0xFF]; signed bytes saturate to [0x80, 0x7F]; unsigned half-words saturate to [0, 0xFFFF]; signed half-words saturate to [0x8000, 0x7FFF]; unsigned words saturate to [0, 0xFFFF FFFF]; and signed words saturate to [0x8000 0000, 0x7FFF FFFF]. If the saturation field **1905** is 0, then histogram bin entries do not saturate to min/max values of the element data type and instead will wrap around when incremented beyond a maximum value or decremented beyond a minimum value.

[0218] Extensions of the above-described histogram and weighted histogram instructions in response to different parameters specified by the configuration register **1900** should be apparent to one of ordinary skill in the art. For example, changes to the number of tables (or histograms) field

1908 affects the number of indexes specified by the vector source index register **2102** (e.g., as shown in FIGS. **21-25**). Similarly, changes to the weight size field **1903** affects the portion of the vector source data register **3502** that provides source data to be written to the indexed bin entries of the histograms.

[0219] In the foregoing discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to . . .” Also, the term “couple” or “couples” is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection or through an indirect connection via other devices and connections. Similarly, a device that is coupled between a first component or location and a second component or location may be through a direct connection or through an indirect connection via other devices and connections. An element or feature that is “configured to” perform a task or function may be configured (e.g., programmed or structurally designed) at a time of manufacturing by a manufacturer to perform the function and/or may be configurable (or re-configurable) by a user after manufacturing to perform the function and/or other additional or alternative functions. The configuring may be through firmware and/or software programming of the device, through a construction and/or layout of hardware components and interconnections of the device, or a combination thereof. Additionally, uses of the phrases “ground” or similar in the foregoing discussion are intended to include a chassis ground, an Earth ground, a floating ground, a virtual ground, a digital ground, a common ground, and/or any other form of ground connection applicable to, or suitable for, the teachings of the present disclosure. Unless otherwise stated, “about,” “approximately,” or “substantially” preceding a value means ± 10 percent of the stated value.

[0220] The above discussion is meant to be illustrative of the principles and various embodiments of the present disclosure. Numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated.

[0221] It is intended that the following claims be interpreted to embrace all such variations and modifications.

Claims

1. A device, comprising: a memory capable of storing a set of tables; and a processor functional unit coupled to the memory and capable of: receiving a table write instruction that indicates a first register storing a set of indices each associated with one of the set of tables, a second register storing a base address of the set of tables, and a third register storing a set of data elements; and in response to the table write instruction, writing each data element of the set of data elements to a corresponding table of the set of tables based on the base address and an index of the set of indices that is associated with the corresponding table.
2. The device of claim 1, wherein the memory is a level one (L1) data cache.
3. The device of claim 1, wherein to write each data element to the corresponding table, the processor functional unit is capable of: determining an element of the corresponding table based on the base address and the index associated with the corresponding table; and writing the data element to the element of the corresponding table.
4. The device of claim 3, wherein: the index represents an offset address relative to the base address; and the processor functional unit is capable of determining the element based on adding the offset address to the base address.
5. The device of claim 1, wherein: the set of tables is a first set of tables; the memory is capable of storing a second set of tables; and the processor functional unit is further capable of: receiving a table initialization instruction that indicates an index associated with the second set of tables, the second set of tables, and a data element; and in response to the table initialization instruction, write a duplicate of the data element to each table of the second set of tables based on the index

associated with the second set of tables.

6. The device of claim 1, further comprising a table enable register storing an indication of which operation is allowed on the set of tables.

7. The device of claim 1, further comprising a configuration register storing configuration associated with the set of tables.

8. The device of claim 7, wherein the configuration indicates a size of each of the set of data elements.

9. The device of claim 7, wherein the configuration indicates a size of each of the set of tables.

10. The device of claim 7, wherein the configuration indicates a number of tables in the set of tables.

11. A method, comprising: receiving a table write instruction that indicates a first register storing a set of indices each associated with one of a set of tables, a second register storing a base address of a set of tables, and a third register storing a set of data elements; and in response to the table write instruction, writing each data element of the set of data elements to a corresponding table of the set of tables based on the base address and an index of the set of indices that is associated with the corresponding table.

12. The method of claim 11, wherein the set of tables is stored in a level one data cache.

13. The method of claim 11, wherein writing each data element to the corresponding table comprises: determining an element of the corresponding table based on the base address and the index associated with the corresponding table; and writing the data element to the element of the corresponding table.

14. The method of claim 13, wherein: the index represents an offset address relative to the base address; and determining the element of the corresponding table comprises determining the element based on adding the offset address to the base address.

15. The method of claim 11, wherein: the set of tables is a first set of tables; and the method comprises: receiving a table initialization instruction that indicates an index associated with a second set of tables, the second set of tables, and a data element; and in response to the table initialization instruction, writing a duplicate of the data element to each table of the second set of tables based on the index associated with the second set of tables.

16. The method of claim 11, further comprising obtaining an indication from a table enable register that indicates which operation is allowed on the set of tables.

17. The method of claim 11, further comprising obtaining configuration associated with the set of tables from a configuration register.

18. The method of claim 17, wherein the configuration indicates a size of each of the set of data elements.

19. The method of claim 17, wherein the configuration indicates a size of each of the set of tables.

20. The method of claim 17, wherein the configuration indicates a number of tables in the set of tables.
