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## Macintosh Quadra 650 and 800: Interleaved Memory (7/94)

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TOPIC -----

The Macintosh Centris 650, and Quadra 800 computers feature a newly designed memory controller that supports interleaved memory. The following article explains how interleaved memory works on these computers and how to configure the computers for maximum performance.

The Quadra 650 can be used interchangeably with the Centris 650 in this document.

DISCUSSION -----

Note that as of this date, the Centris 650 and Quadra 800 are the only Macintosh models that support memory interleaving. Neither the Centris 66AV nor the Quadra 840AV support memory interleaving.

Interleaved Memory on the Centris 650 and Quadra 800

The main memory subsystem of the Macintosh Centris 650 and Quadra 800 computers makes use of a memory access technique called interleaved memory. This memory organization serves to reduce the overall access time of the 68040 processor into DRAM. The following description illustrates how this memory organization works and why it results in reduced memory access time.

Non-Interleaved Memory System

In a non-interleaved memory system, all of the first bank of memory, bank 0, is addressed before the first long word of the second bank of memory, bank 1, all of bank 1 is addressed before the first long word of bank 2, and so on. Figure 1 shows this organization for two banks of N long words. (A long word is 4 bytes, or 32 bits, and is the natural unit of memory for the 68040.)

Bank 0

Bank 1

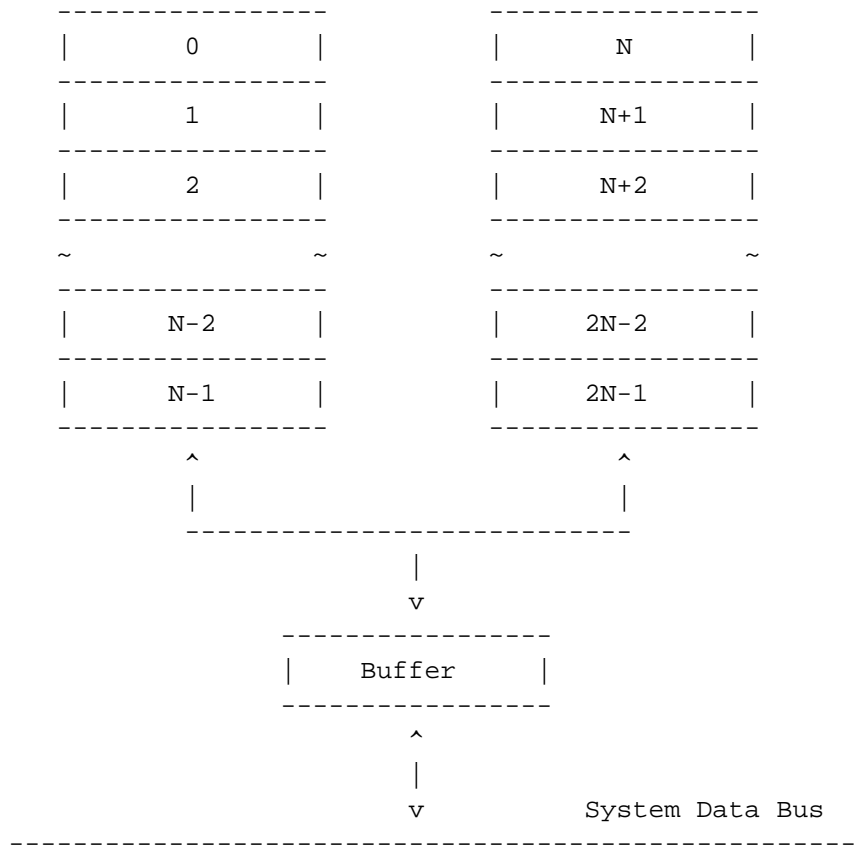


Figure 1. Non-interleaved Memory Organization

The 68040 performs burst accesses (a single bus transaction that reads or writes 16 bytes in 4 adjacent long words) to move data between its caches and memory. All 16 bytes come from one bank of DRAM in a non-interleaved memory system, so the time required to complete the transfer depends directly on the access time of the DRAM. Figure 2 shows an example of such a burst access. The time needed to access the 2nd, 3rd, and 4th long words is shorter because it uses a DRAM feature called "page-mode access."

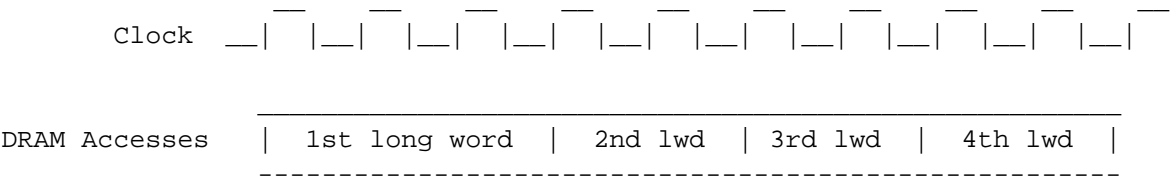


Figure 2. Non-interleaved Burst Access Timing

Interleaved Memory System

In an interleaved memory system, there are still two physical banks of DRAM, but logically the system sees one bank of memory that's twice as large. In the interleaved bank, the first long word of bank 0 is followed by the first long word of bank 1, which is followed by the second long word of bank 0, which is followed by the second long word of bank 1, and so on. Figure 3 shows this organization for two physical banks of N long words. All even long words of the

logical bank are located in physical bank 0 and all odd long words are located in physical bank 1.

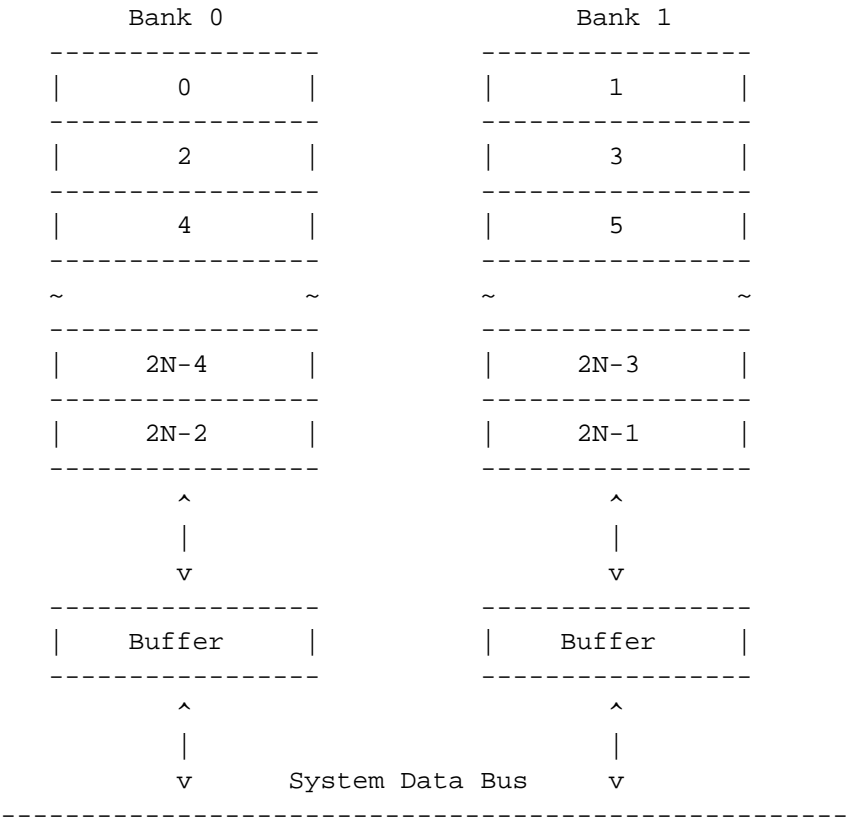


Figure 3. Interleaved Memory Organization

The interleaved memory configuration is designed to speed up 68040 burst accesses by as much as 30%. (The actual improvement depends on the system clock speed and the DRAM access time.) Since the four long words of a burst access are spread across two physical banks of DRAM, the individual accesses can be overlapped to hide part, or all, of the DRAM access time delay, as shown below in Figure 4.

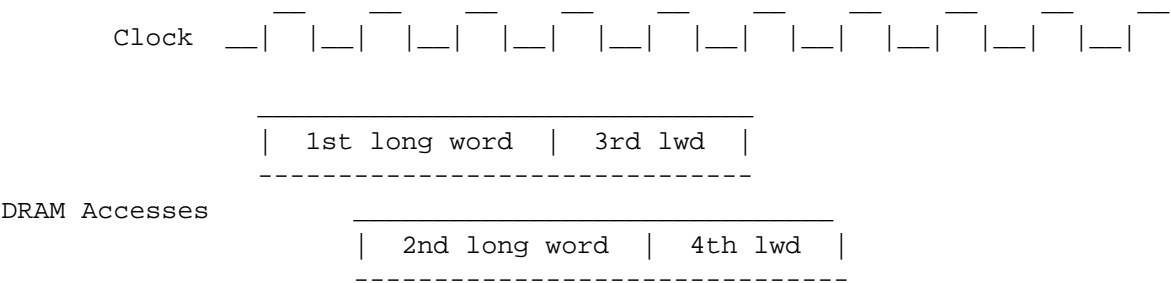


Figure 4. Interleaved Burst Access Timing

Centris 650 and Quadra 800 Memory Organization

Physically, the DRAM in a Centris 650 or Quadra 800 system is organized as 110 banks of memory, where each bank is 32 bits wide and 4MB or 16MB deep.

Logically, the DRAM is organized as 5 pairs of banks, any of which may or may not be interleaved. At system boot time, each pair of DRAM banks is examined; if they are the same size (4MB or 16 MB), the interleaved memory configuration for that bank pair will be enabled. Otherwise, the bank pair will be left in the non-interleaved configuration.

The memory controller in the Centris 610 or Quadra 800 is capable of operating with some bank pairs in the interleaved configuration and some bank pairs in the non-interleaved configuration. The type of memory access performed is determined dynamically at the start of each cycle based on the value of an "interleave configuration register" within the memory controller. ROM accesses can't be interleaved since there's only a single bank of ROM.

The Centris 650 and Quadra 800 main logic board contains 4MB or 8MB of DRAM and 4 DRAM SIMM sockets. Systems that contain 8MB on the main logic board (all Quadra 800 and some Centris 650 computers) already interleave the two 4MB banks soldered to the main logic board. Systems which have only 4MB soldered on the main logic board can't interleave the single soldered 4MB DRAM bank, although DRAM on SIMMs can still be interleaved.

Each DRAM SIMM can contain either one or two banks of DRAM. The Centris 650 and Quadra 800 use 72-pin DRAM SIMMs; these SIMMs have a 32-bit data path, allowing memory upgrades to be performed with a single SIMM. Single-sided SIMMs contain one DRAM bank; double-sided SIMMs contain two DRAM banks. A double-sided SIMM can't contain an interleaved bank pair since there aren't enough pins on the SIMM to accommodate the two 32-bit data buses required for interleaved memory. Interleaving can only be done between DRAM SIMM pairs.

The main logic board contains banks 0 and 1, SIMM slot 1 contains banks 2 and 3 (remember, SIMMs can be double-sided and contain 2 banks of DRAM), slot 2 contains banks 4 and 5, slot 3 contains banks 6 and 7, and slot 4 contains banks 8 and 9. SIMM slot pairs 1-2 and 3-4 are interleaved together whenever a bank pair is of the same size. For example, if 4MB SIMMs are placed in both SIMM slots 1 and 2, then that memory will be interleaved (banks 2 and 4). If a double-sided 8MB SIMM (that is, a SIMM with two 4MB banks on it) is placed in slot 1, and a single-sided 4MB SIMM is placed in bank 2, then two of the banks will be interleaved (banks 2 and 4) and one bank won't be interleaved (bank 3).

The gist of all this is that in order to maximally enable memory interleaving, memory upgrades should be performed with a pair of SIMMs, both of the same size.

A single SIMM can be used for memory expansion, but will result in a portion of memory being non-interleaved. The system actually takes care of configuring everything automatically at boot, regardless of what memory is installed. However, by physically configuring DRAM in identically sized bank pairs, the fastest overall memory access is achieved (that is, the highest performance). The actual performance delta between an interleaved and non-interleaved memory system will depend on the application, and will vary from application to application.

#### Article Change History:

28 Jul 1994 - Added note that Centris 650 and Quadra 650 are interchangeable in this article.

20 Aug 1993 - Added note at top.

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