PCI Bus Binding to

IEEE 1275-1994
Standard for Boot (Initialization, Configuration) Firmware

Revision 1.5
DRAFT

20 March, 1995

1   **Foreword by the Chairman of the IEEE 1275 Working Group**
2   (This foreword is not a part of the Specification.)

Introduction

4   Firmware is the ROM-based software that controls a computer between the time it is turned on and the time the
5   primary operating system takes control of the machine. Firmware's responsibilities include testing and
6   initializing the hardware, determining the hardware configuration, loading (or booting) the operating system, and
7   providing interactive debugging facilities in case of faulty hardware or software.

Historical Perspective

9   Historically, firmware designs have been proprietary and often specific to a particular bus or instruction set
10   architecture (ISA). This need not be the case. Firmware can be designed to be machine-independent and easily
11   portable to different hardware. There is a strong analogy with operating systems in this respect. Prior to the
12   advent of the portable UNIX operating system in the mid-seventies, the prevailing wisdom was that operating
13   systems must be heavily tuned to a particular computer system design and thus effectively proprietary to the
14   vendor of that system.

15   The *IEEE 1275-1994 Standard for Boot (Initialization, Configuration), Core Requirements and Practices* (referred
16   to in the remainder of this document as Open Firmware) specification is based on Sun Microsystem's OpenBoot
17   firmware. The OpenBoot design effort began in 1988, when Sun was building computers based on three different
18   processor families, thus OpenBoot was designed from the outset to be ISA-independent (independent of the
19   Instruction Set Architecture). The first version of OpenBoot was introduced on Sun's SPARCstation 1
20   computers. Based on experience with those machines, OpenBoot version 2 was developed, and was first shipped
21   on SPARCstation 2 computers. This standard is based on OpenBoot version 2.

Purpose and Features of the Open Firmware Specification

23   Open Firmware has the following features:

24   Mechanism for loading and executing programs (such as operating systems) from disks, tapes, network
25   interfaces, and other devices.

26   ISA-independent method for identifying devices "plugged-in" to expansion buses, and for providing firmware
27   and diagnostics drivers for these devices.

28   An extensible and programmable command language based on the Forth programming language.

29   Methods for managing user-configurable options stored in non-volatile memory.

30   A "call back" interface allowing other programs to make use of Open Firmware services.

31   Debugging tools for hardware, firmware, firmware drivers, and system software.

Purpose of this Bus Binding

33   This document specifies the application of Open Firmware to the PCI Local Bus, including PCI-specific
34   requirements and practices for address format, interrupts, probing, and related properties and methods.

35   The core requirements and practices specified by Open Firmware must be augmented by system-specific
36   requirements to form a complete specification for the firmware for a particular system. This document establishes
37   such additional requirements pertaining to PCI.

1   **Task Group Members**

2   The following individuals were members of the Task Group that produced this document:

3   Ron Hochsprung, Apple Computer, Inc.

4   Mitch Bradley, FirmWorks (Chair, IEEE P1275 Working Group)

5   David Kahn, Sun Microsystems, Inc. (Vice Chair, IEEE P1275 Working Group)

6

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16   product names as designated by the companies who market those products. Inquiries concerning such trademarks
17   should be made directly to those companies.

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19   **Revision History**

20 21	**Revision 0.1 Oct. 7, 1993**	First revision distributed outside of task group (the number 0.1 did not appear on the cover).
22 23 24	**Revision 0.2 Oct. 28, 1993**	Changed the designator for 64-bit memory space from "M" to "x". Changed the parts of the specification related to PCI to PCI bridges to reflect the 0.4 bridge architecture spec.
25 26	**Revision 1.0 April 14, 1994**	Changed references from P1275 to Open Firmware. Changed size of fields for I/O address representations to reflect PCI architecture.
27	**Revision 1.1 June 28, 1994**	Added 't'-bit for aliasing, and discussion of "hard-decode" cases.
28 29 30	**Revision 1.2 August 7, 1994**	Added note about DD encoding. Added new standard properties for those of draft Rev 2.1 PCI spec. Deleted enabling of Memory space at post-probe. Added driver encapsulation description.
31 32	**Revision 1.3 September 27, 1994**	Changed generated name for Subsystem, if present. Added rule for I/O assignment. Added discussion of PCI-PCI bridge probing.
33 34	**Revision 1.4 December 16, 1994**	Added Expansion ROM address assignment, 't' bit for "below 1 MB".
35 36	**Revision 1.5 March 20, 1995**	Added Legacy devices section, "clock-frequencey" property, clarified address assignment, added 't' bit for relocatable I/O space.

1   **Overview and References**

2   This specification describes the application of Open Firmware to computer systems that use the PCI Local bus

3   as defined in *PCI Local Bus Specification, Revision 2.0, April 30, 1993* and *PCI to PCI Bridge Architecture*

4   *Specification, Revision 1.0 April 5, 1994* and is to be used in conjunction with those documents.

5   *Note: this version applies to Revisision 2.1 which is currently undergoing review.*

6   **Definitions of Terms**

7   **bus controller:** a hardware device that implements a PCI bus.

8   **hard decode:** a decoding which is not based upon a base register, but, rather, is fixed.

9   **PCI device:** a hardware device that connects to or "plugs in" to a PCI bus PCI function: one of a number of

10   logically-independent parts of a PCI device. Many PCI devices have only one function per device; in such cases,

11   the terms "PCI function" and "PCI device" can be used interchangeably.

12   **PCI to PCI bridge:** a hardware device that is, from an electrical standpoint, a single PCI function on one

13   PCI bus (the "parent" bus) and the bus controller of a secondary PCI bus (the "child" bus).

14   **PCI domain:** a group of PCI buses connected together in a tree topology by PCI to PCI bridges.

15   **relocatable region:** a range of PCI address space whose base address is established by a single base address register.

16   **Master PCI bus:** within a PCI domain, the PCI bus that forms the root of the tree structure.

17   **bus node:** an Open Firmware device node that represents a bus controller. In cases where a node represents the

18   interface, or "bridge", between one bus and another, the node is both a bus node relative to the bus it controls,

19   and a child node of its parent bus. Note that an Open Firmware device node is not in itself a physical hardware

20   device; rather, it is a software abstraction that describes a hardware device.

21   **child node:** an Open Firmware device node that represents a PCI function. Such a node can correspond to

22   either a device that is "hardwired" to a planar PCI bus, or to an "add in" expansion card that is plugged into a

23   standard PCI Expansion Connector.

24   **Bus Characteristics**

25   **Address Spaces**

26   PCI has several address spaces (Memory, I/O, Configuration), with different addressing characteristics.

27   **Memory Space**

28   Memory Space is the primary address space of PCI; it corresponds to traditional memory and "memory-mapped"

29   I/O. PCI allows for a full 64-bit address range in Memory Space; however, most devices will not require a full

30   64-bit range. In order to provide compatibility between devices designed for 64-bit addressing and those for 32-

31   bit addressing, the 32-bit address space appears as the first 4 GB region of the 64-bit space; i.e., 64-bit addresses

32   with the 32 most-significant bits equal to 0 are used to access 32-bit devices. 64-bit initiators are required to use

33   the 32-bit address protocol for any 64-bit address in which the upper 32 bits are all 0.

34   The PCI specification requires that all of a device's relocatable resources must be mappable in Memory Space,

35   i.e. it is not permissible for a resource to be mappable only in I/O Space (described below).

36   The regions of Memory Space to which a PCI device responds are assigned dynamically during system

37   initialization, by setting device base address registers in Configuration Space (see below). The size of each such

38   region must be a power of two, and the assigned base address must be aligned on a boundary equal to the size of

39   the region.

40   And encoding of the base address registers for Memory Space allow a resource to require address allocation within

41   the first 1 MB. This requirement is reflected in the **`reg`** property entry for that base register by having the

42   `'t'` bit set.

1 Memory Space addressing is "flat" across a PCI domain, in that addresses are not transformed as they cross PCI
2 to PCI bridges. The flat address space is not necessarily limited to a single PCI domain; the PCI design attempts
3 to make it possible to have a flat address across multiple PCI domains that are peers of one another on a higher-
4 level host address bus.

5 An early revision of the PCI specification admitted the possibility that some devices might respond to fixed
6 (non-relocatable) address ranges. The current revision permits this behavior for VGA and IDE devices, but it is
7 possible that some other devices still behave that way. The current specification allows devices to respond to
8 fixed addresses after a system reset, but provides a standard way to disable such response, which devices are
9 required to implement.

10 **I/O Space**

11 I/O Space is similar to Memory Space, except that it is intended as to be used with the special "I/O access"
12 instructions that some processors have. As with Memory Space, I/O Space addresses are assigned dynamically
13 during system initialization, and the addressing is "flat" across a PCI domain.

14 Relocatable   I/O   Space   *shall*   be   allocated   at   addresses   of   the   form
15 `aaaa.aaaa.aaaa.aaaa.aaaa.aa00.aaaa.aaaa`. This guarantees that relocatable I/O addresses will not conflict
16 with hard-decoded address that have non-zero bits in AD[9…8]. Because PCI-PCI bridges restrict I/O address
17 space to 16 bits, relocatable I/O Space across PCI-PCI bridges *shall* be of the form
18 `0000.0000.0000.0000.aaaa.aa00.aaaa.aaaa`.

19 *Note: although the PCI specification allows 32-bit I/O Space addresses, many of the processors that have special*
20 *I/O access instructions present only a 16-bit I/O address. However, Open Firmware allows for the specification*
21 *of the full 32-bit range.*

22 PCI also allows devices to have I/O base address registers that implement only the low-order 16 bits. I.e., the
23 upper 16 bits are assumed to be 0. When probing, after writing all 1s, the data read back will have the high-order
24 16 bits equal to 0, while the low-order 16 bits will reflect the address space requirement. Address space for such a
25 base register must be allocated within the first 64 KB of I/O Space. This requirement is reflected in the **"reg"**
26 property for that base register by having the `'t'`-bit set. This is interpretation of the `'t'`-bit for I/O Space is
27 distinquished from the "alias" case by having the `'n'`-bit equal to 0 in its **"reg"** entry; the corresponding
28 **"assigned-addresses"** entry *shall* have the `'t'`-bit equal to 0.

29 **Hard-decoded Spaces**

30 PCI allows devices to "hard-decode" Memory and I/O addresses; i.e., the addresses are not subject to relocation
31 via a base register. These address ranges are represented by having the non-relocatable bit (`'n'`) set in their
32 corresponding **"reg"** and **"assigned-addresses"** properties, where the base-register field of the
33 *phys.hi* is 0.

34 Furthermore, such devices are allowed to "alias" their hard-decoded I/O addresses by ignoring all but the lower 10
35 bits of an I/O address. To conserve **"reg"** property space, a bit (the `'t'`-bit, for ten-bit) is included in the
36 encoding of hard-decoded (non-relocatable, `'n'`-bit = 1) I/O address **"reg"** and **"assigned-**
37 **addresses"** entries to indicated that the address range includes all such aliases.

38 **Configuration Space**

39 Configuration Space is used primarily during device initialization. Each device contains a set of Configuration
40 Registers which are used to identify and configure the device. Configuration Cycles access a device's
41 Configuration Registers, including the "address base registers" which must be initialized before the device will
42 respond to Memory and I/O Space accesses.

43 In contrast to Memory and I/O Space addressing, Configuration Space addressing is effectively "geographical", in
44 that the Configuration Space address of a particular device is determined by its physical location on a PCI bus
45 (i.e. the slot in which it is installed), or more generally, its physical location within a "tree" of interconnected
46 PCI to PCI bridges.

1   The method for generating Configuration Cycles is system-dependent. In some systems, special registers are
2   used to generate Configuration Space cycles. In other systems, Configuration Space might be memory-mapped
3   as a region within a large physical address space. In particular, the hardware method for specifying the Bus
4   Number and Device Number is system-dependent. Bus Number and Device Number are described below as
5   though they are binary-encoded fields within an address; in practice, that is not necessarily true at the hardware
6   level. However, the representation described below is adequate as an internal software representation, because it
7   is capable of representing the entire possible space of PCI Configuration Space addresses.

8   A Configuration Space address consists of several fields:

9   **Bus Number: 8 bits.**

10 Each PCI bus within a PCI domain is assigned a unique identifying number, known as the "bus number". The
11 assignments occur during system initialization, when the bus controllers for the PCI buses within the PCI
12 domain are located. The bus number for a particular bus is written into a register in that bus's bus controller.

13 During a Configuration Cycle, each bus controller compares the bus number field of the address to its assigned
14 bus number. If they match, the bus controller selects one of the devices on its PCI bus, according to the value
15 of the Device Number field. Otherwise, the bus controller either forwards the configuration cycle to its
16 subordinate PCI to PCI bridges (if the bus number is for one of its subordinate bridges) or ignores the cycle.

17 **Device Number: 5 bits**

18 During a Configuration Cycle, the bus controller selected by the bus number field decodes the Device Number
19 field, activating the single corresponding "IDSEL" device select line to enable one of the PCI devices on that
20 bus. For PCI buses with plug-in slots, the Device Number field effectively selects a particular slot. Electrical
21 limitations restrict the number of devices on an individual PCI bus to fewer than the 32 that could otherwise be
22 selected by this 5-bit field.

23 Some PCI bus controllers use the same physical wires for the IDSEL lines and higher-numbered address lines,
24 thus, on the bus that is selected by the bus number field, the Device Number does not appear on the address bus
25 in its 5-bit binary-encoded form. Rather, the 5-bit field is decoded to a "one of n" select that asserts exactly one
26 upper address line. This fact does not affect the logical representation of the Device Number as a 5-bit binary-
27 encoded field.

28 *Note: the decoding mechanism (e.g., the address bit selected) from the Device Number is system dependent.*
29 *Furthermore, the implementation of the Open Firmware* **config-xx** *words can "hide" this detail. However,*
30 *it is recommended that an Open Firmware implementation choose a numbering which is meaningful to the user.*

31 **Function Number: 3 bits**

32 Each PCI device can have from one to eight logically-independent functions, each with its own independent set of
33 configuration registers. A PCI device that is selected during a Configuration Cycle decodes the Function Number
34 field to select the appropriate set of configuration registers for that function. The assignment of Function
35 Numbers to particular functions is a hard-wired characteristic of the individual PCI device. For a PCI device with
36 only one function, the Function Number must be zero.

37 **Register Number: 8 bits**

38 The register number field, decoded by the PCI device, selects a particular register within the set of configuration
39 registers corresponding to the selected function. The layout (locations and meanings of particular bits) of the
40 first few configuration registers (i.e. those with small register numbers) is specified by the PCI standard; other
41 configuration registers are device-specific. The standard configuration registers perform such functions as
42 assigning Memory Space and I/O Space base addresses for the device's addressable regions.

43 In many PCI hardware implementations, Configuration Space does not appear as a direct subset of the system's
44 physical address space; instead, Configuration Space accesses are performed by a sequence of reads or writes to
45 special system registers.

1   **"Address-less" Cycles**

2   In addition to these address spaces, PCI has two types of transactions in which the address bus is not used.
3   Special Cycles (writes) are "broadcast" cycles in which the data conveys all of the information. Interrupt
4   Acknowledge Cycles (reads) are intended to support interrupt control hardware associated with PCI devices. The
5   PCI specification does not specify the details of such interrupt control hardware.

6   **Low-order Address Bits**

7   The address characteristics described above do not take into account the way that the PCI bus uses the least-
8   significant two address bits. In general, at the hardware level, the PCI bus uses the two low address bits
9   (AD[1::0]) not to identify the particular byte to be accessed, but instead to convey additional information about
10   the data transfer, such as the type of address incrementing for burst transfers. The bytes are selected with "byte
11   enable" signals.

12   That hardware subtlety is irrelevant for the purposes of this specification; within the Open Firmware domain,
13   addresses identify individual 8-bit, 16-bit, and 32-bit registers or memory locations in the usual way. Within
14   this document, "address" refers to that software view of an address, which in the case of the two lower address bits
15   is not necessarily the same as what is on the PCI address wires.

16   **Address Formats and Representations**

17   **Physical Address Formats**

18   **Numerical Representation**

19   (The Numerical Representation of an address is the format that Open Firmware uses for storing an address within
20   a property value and on the stack, as an argument to a package method.) The numerical representation of a PCI
21   address consists of three cells, encoded as follows. For this purpose, the least-significant 32 bits of a cell is
22   used; if the cell size is larger than 32 bits, any additional high-order bits are zero. Bit# 0 refers to the least-
23   significant bit.

```
24              Bit#:  33222222 22221111 11111100 00000000
25                     10987654 32109876 54321098 76543210

26   phys.hi cell:  npt000ss bbbbbbbb dddddfff rrrrrrrr
27   phys.mid cell: hhhhhhhh hhhhhhhh hhhhhhhh hhhhhhhh
28   phys.lo cell:  llllllll llllllll llllllll llllllll
```

29   where:

30   n   is 0 if the address is relocatable, 1 otherwise
31   p   is 1 if the addressable region is "prefetchable", 0 otherwise
32   t   is 1 if the address is aliased (for non-relocatable I/O), below 1 MB (for Memory),
33   or below 64 KB (for relocatable I/O).
34   ss   is the space code, denoting the address space
35   bbbbbbbb   is the 8-bit Bus Number
36   ddddd   is the 5-bit Device Number
37   fff   is the 3-bit Function Number
38   rrrrrrrr   is the 8-bit Register Number
39   hh..hh   is a 32-bit unsigned number
40   ll..ll   is a 32-bit unsigned number

41   When the hh..hh and ll..ll fields are concatenated to form a larger number, hh..hh is the most
42   significant portion and ll..ll is the least significant portion.

43   The 'p' bit reflects the state of the "P" bit in the corresponding hardware Base Address register.

1   **Encoding of type code "ss":**

2   00 denotes Configuration Space, in which case:

3   n must be zero

4   p must be zero

5   t must be zero

6   bbbbbbbb,ddddd,fff,rrrrrrrr   is the Configuration Space address

7   hh..hh,ll..ll   must be zero

8

9   01 denotes I/O Space, in which case:

10   p must be zero

11   t is set if 10-bit aliasing is present (for non-relocatable),

12   or below 64 KB required (for relocatable).

13   bbbbbbbb,ddddd,fff,rrrrrrrr   identifies the region's Base Address Register

14   rrrrrrrr can be 0x10, 0x14, 0x18, 0x1c, 0x20 or 0x24 (for relocatable)

15   rrrrrrrr is 0x00 for non-relocatable

16   hh..hh   must be zero

17   If n is 0:   ll..ll   is the 32-bit offset from the start of the relocatable region of I/O

18   Space

19   If n is 1:   ll..ll   is the 32-bit I/O Space address

20

21   10 denotes 32-bit-address Memory Space, in which case:

22   p may be either 0 or 1

23   t is set if an address below 1 MB is required

24   bbbbbbbb,ddddd,fff,rrrrrrrr   identifies the relocatable region's Base Address Register

25   rrrrrrrr can be 0x10, 0x14, 0x18, 0x1c, 0x20, 0x24, 0x30 (relocatable)

26   rrrrrrrr is 0x00 for non-relocatable

27   hh..hh   must be zero

28   If n is 0:   ll..ll   is the 32-bit offset from the start of the relocatable region of 32-bit address Memory Space

29   If n is 1:   ll..ll   is the 32-bit Memory Space address

30

31   11 denotes 64-bit-address Memory Space, in which case:

32   p may be either 0 or 1

33   t must be 0

34   bbbbbbbb,ddddd,fff,rrrrrrrr   identifies the first register of the relocatable region's Base Address

35   Register pair. rrrrrrrr can be 0x10, 0x14, 0x18, 0x1c, or 0x20

36   If n is 0:   hh..hh,ll..ll   is the 64-bit offset from the start of the relocatable region of 64-bit

37   address Memory Space to the start of the subregion

38   If n is 1:   hh..hh,ll..ll   is the 64-bit Memory Space address

39   *Note: Although the bit format of the phys.hi cell is generally consistent with the bit format of a particular kind*

40   *of hardware mechanism for Configuration Space access that is recommended by the PCI standard, the use of that*

41   *format does not imply that the hardware must use the same format. The numerical representation specified herein*

42   *contains the information needed to select a particular hardware device, specifying the format by which that*

43   *information is communicated among elements of Open Firmware firmware and client programs. A driver for a*

44   *particular PCI bus hardware implementation is free to extract that information and reformat as necessary for the*

45   *hardware.*

46   *Note: Although the* PCI Local Bus Specification *defines both prefetchable and non-prefetchable 64-bit-address*

47   *Memory Space, the* PCI to PCI Bridge Architecture Specification *does not specify a standard means of*

48   *supporting non-prefetchable 64-bit-address Memory Space across PCI to PCI bridges.*

49   **Text Representation**

50   The text representation of a PCI address is one of the following forms:

51   DD

52   DD,F

53   [n]i[t]DD,F,RR,NNNNNNNN

1   [n]m[t][p]DD,F,RR,NNNNNNNN
2   [n]x[p]DD,F,RR,NNNNNNNNNNNNNNNN

3   where:
4   DD   is an ASCII hexadecimal number in the range 0..1F
5   F   is an ASCII numeral in the range 0..7
6   RR   is an ASCII hexadecimal number in the range 0..FF
7   NNNNNNNN   is an ASCII hexadecimal number in the range 0..FFFFFFFF
8   NNNNNNNNNNNNNNNN   is an ASCII hexadecimal number in the range 0..FFFFFFFFFFFFFFFF

9   [n]   is the letter 'n', whose presence is optional
10   [t]   is the letter 't', whose presence is optional
11   [p]   is the letter 'p', whose presence is optional
12   i   is the letter 'i'
13   m   is the letter 'm'
14   x   is the letter 'x'
15   ,   is the character ',' (comma)

16   The correspondence between the text representations and numerical representation is as follows:

17   DD

18   corresponds to a Configuration Space address with the numerical value:
19   ss   is 00
20   bbbbbbbb   is the parent's bus number
21   ddddd   is the binary encoding of DD
22   fff   is zero
23   rrrrrrrr   is zero
24   hh..hh   is zero
25   ll..ll   is zero

26   DD,F

27   corresponds to a Configuration Space address with the numerical value:
28   ss   is 00
29   bbbbbbbb   is the parent's bus number
30   ddddd   is the binary encoding of DD
31   fff   is the binary encoding of F
32   rrrrrrrr   is zero
33   hh..hh   is zero
34   ll..ll   is zero

1   [n]i[t]DD,F,RR,NNNNNNNN

2   corresponds to a relocatable (if 'n' is not present) or a non-relocatable (if 'n' is present) 32-bit I/O
3   Space address with the numerical value. If 't' is present, only the low-order 10 bits of an I/O
4   address range is indicated; aliases are assumed to for all high-order bits. The numerical value is:
5   ss   is 01
6   bbbbbbbb   is the parent's bus number
7   ddddd   is the binary encoding of DD
8   fff   is the binary encoding of F
9   rrrrrrrr   is the binary encoding of RR
10   hh..hh   is zero
11   ll..ll   is the binary encoding of NNNNNNNN

12   [n]m[t][p]DD,F,RR,NNNNNNNN

13   corresponds to a relocatable (if 'n' is not present) or a non-relocatable (if 'n' is present) 32-bit
14   Memory Space address. If 't' is present, the address is within the first 1 MB of memory address
15   space.   The the numerical value is:
16   ss   is 10
17   bbbbbbbb   is the parent's bus number
18   ddddd   is the binary encoding of DD
19   fff   is the binary encoding of F
20   rrrrrrrr   is the binary encoding of RR
21   hh..hh   is zero
22   ll..ll   is the binary encoding of NNNNNNNN

23   [n]x[p]DD,F,RR,NNNNNNNNNNNNNNNN

24   corresponds to a relocatable (if 'n' is not present) or a non-relocatable (if 'n' is present) 64-bit
25   Memory Space address with the numerical value:
26   ss   is 10
27   bbbbbbbb   is the parent's bus number
28   ddddd   is the binary encoding of DD
29   fff   is the binary encoding of F
30   rrrrrrrr   is the binary encoding of RR
31   hh..hh,ll..ll   is the binary encoding of NNNNNNNNNNNNNNNN

32   Conversion of hexadecimal numbers from text representation to numeric representation shall be case-insensitive,
33   and leading zeros shall be permitted but not required.

34   Conversion from numeric representation to text representation shall use the lower case forms of the hexadecimal
35   digits in the range `a..f`, suppressing leading zeroes, and the DD form shall be used for Configuration Space
36   addresses where `fff` is zero.

37   **Unit Address Representation**

38   As required by this specification's definition of the **"reg"** property, a function's "unit-number" (i.e. the first
39   component of its **"reg"** value) is the Configuration Space address of the function's configuration registers.
40   Since the "unit-number" is the address that appears in an Open Firmware 'device path', it follows that only the
41   DD and DD,FF forms of the text representation can appear in a 'device path'.

42   *Note: Since the predominant use of the text representation is within 'device paths', text representations of I/O*
43   *and Memory Space addresses are rarely seen by casual users.*

44   *Note: The bus number does not appear in the text representation. If the bus number were present, then the*
45   *pathname of a particular device would depend on the particular assignment of bus numbers to bus controllers, so*
46   *the pathname could change if PCI to PCI bridges were added or removed from other slots. (It is generally*
47   *undesirable for the pathname of a particular device to depend on the presence or absence of other devices that are*
48   *not its ancestors in the device tree.) The combination of a device node's position in the device tree, its Device*

1   *Number and its Function Number uniquely select an individual function based on physical characteristics of the*
2   *system, so the function's pathname does not change unless the device is physically moved.*

3   *Note: The bus number appears in the numerical representation because that makes it easier to implement*
4   *Configuration Space access methods. The* **`decode-unit`** *method automatically inserts the bus number in*
5   *the numerical representation; it can do so because each bus node knows the bus number of the bus it represents.*

6   Open Firmware implications:

7   Since some processors cannot generate I/O cycles directly, I/O Space accesses must be done with the register
8   access words (e.g., **`rb@`**, **`rw!`**).

9   It is recommended that a range of virtual addresses be set aside for use by **map-in** to I/O Space devices so that
10 the register access words can determine when an I/O cycle needs to be generated.

11 Since Configuration Space often does not appear as a subset of the system's physical address space, this firmware
12 specification provides bus-specific methods to access Configuration Space. Likewise, it provides methods for
13 Special Cycles and Interrupt Acknowledge Cycles.

14 ### Bus-specific Configuration Variables

15 An Open Firmware-compliant User Interface on a system with a single built-in PCI bus *may* implement
16 the following PCI-specific Configuration Variable.

17 **`pci-probe-list`**   (-- list-str list-len)   N
18   Holds list of slots to probe with **`probe-pci`** .

19   A configuration variable containing a string, formatted as described in the following section, indicating the set of
20   slots that will be probed when **`probe-pci`** is executed. The maximum length shall be sufficient to contain a
21   string listing all of the PCI bus's implemented slots.
22   **Configuration Variable Type**: string
23   **Default value**: a system-dependent value that includes all available slots, in numerically-ascending order.
24   *Note:* **`pci-probe-list`** *is intended for the common case of a system with a single built-in PCI bus. On*
25   *systems with multiple PCI buses, fine-grained control over the probe order can be achieved by repeated execution*
26   *of the* **`probe-self`** *method within individual bus nodes. In any case, the ability to control the probe order is*
27   *primarily intended as a convenience when debugging faulty expansion cards. Normally, the default probe order (all*
28   *available slots) is used.*

29 ### Format of a Probe List

30 A PCI probe list is a text string consisting of a series of lower-case hexadecimal numbers separated by commas.
31 Each number is in the range `0..1f`, corresponding to the slot with the same Device Number. For a given PCI
32 bus implementation, only the numbers corresponding to existing slots are valid.

33 The first number in the series specifies the first slot to be probed, and so on.

34 ### FCode Evaluation Semantics

35 See the description of **`probe-pci`** for the precise specification of the FCode evaluation semantics.

36 ### Bus Nodes

37 *Note: A PCI to PCI bridge is a parent of one PCI bus and a child of another. Consequently, a device node*
38 *representing a PCI bridge is both a Bus Node and a Child Node, with both sets of properties and methods.*

39 ### Properties

40 ### Open Firmware-defined Properties for Bus Nodes

41 The following standard properties, as defined in Open Firmware, have special meanings or interpretations for PCI.

1   **"device_type"**   S

2   Standard *prop-name* to specify the implemented interface. prop-encoded-array: a string encoded with **encode-**
3   **string**.

4   The meaning of this property is as defined in Open Firmware. A Standard Package conforming to this specification
5   and corresponding to a device that implements a PCI bus shall implement this property with the string value
6   "pci".

8   **"#address-cells"**   S

9   Standard *prop-name* to define the number of cells necessary to represent a physical address.

10 prop-encoded-array: Integer constant 3, encoded with **encode-int**.

11 The value of **"#address-cells"** for PCI Bus Nodes is 3.
12

13 **"#size-cells"**   S

14 Standard *prop-name* to define the number of cells necessary to represent the length of a physical address range.

15 *prop-encoded-array*: Integer constant 2, encoded as with **encode-int**.

16 The value of **"#size-cells"** for PCI Bus Nodes is 2, reflecting PCI's 64-bit address space.
17

18 **"reg"**   S

19 Standard *prop-name* to define the package's unit-address.

20 For nodes representing PCI to PCI bridges, the **"reg"** property is as defined for PCI Child Nodes. The value
21 denotes the Configuration Space address of the bridge's configuration registers.

22 For bridges from some other bus to PCI bus, the **"reg"** property is as defined for that other bus.
23

24 **Bus-specific Properties for Bus Nodes**

25 **"clock-frequency"**   S

26 *prop-name*, denotes frequency of PCI clock.

27 *prop-encoded-array*: An integer, encoded as with **encode-int**, that represents the clock frequency, in hertz, of
28 the PCI bus for which this node is the parent.
29

30 **"bus-range"**   S

31 *prop-name*, denotes range of bus numbers controlled by this PCI bus.

32 *prop-encoded-array*: Two integers, each encoded as with **encode-int**, the first representing the bus number of
33 the PCI bus implemented by the bus controller represented by this node (the *secondary bus* number in PCI to PCI
34 bridge nomenclature), and the second representing the largest bus number of any PCI bus in the portion of the PCI
35 domain that is subordinate to this node (the *subordinate bus* number in PCI to PCI bridge nomenclature).

36 **"slot-names"**   S

37 *prop-name*, describes external labeling of add-in slots.

38 *prop-encoded-array*: An integer, encoded as with **encode-int**, followed by a list of strings, each encoded as
39 with **encode-string**.

40 The integer portion of the property value is a bitmask of available slots; for each add-in slot on the bus, the bit
41 corresponding to that slot's Device Number is set. The least-significant bit corresponds to Device Number 0, the
42 next bit corresponds to Device Number 1, etc. The number of following strings is the same as the number of slots;
43 the first string gives the label that is printed on the chassis for the slot with the smallest Device Number, and so
44 on.
45

46 **Methods**

47 **Open Firmware-defined Methods for Bus Nodes**

48 A Standard Package implementing the "pci" device type shall implement the following standard methods as
49 defined in Open Firmware, with the physical address representations as specified in section 2.1 of this standard,
50 and with additional PCI-specific semantics:
51 **open**   (-- okay?)   Prepare this device for subsequent use
52 **close**   (--)   Close this previously-open device
53 **map-in**   (phys.low phys.mid phys.hi size -- virt)   Map the specified subregion.

54 PCI to PCI bridges pass through addresses unchanged. Consequently, a PCI to PCI bridge node's implementation of
55 **map-in** typically just forwards the request to its parent.

56 For a master PCI bus node in "probe state", if the physical address is relocatable, the **map-in** method shall assign
57 a base address and set the appropriate base address register to that address. Such "probe state" assignments are
58 temporary and are not necessarily valid after the corresponding **map-out**.

1 **map-out**   (virt size --)   Destroy mapping from previous map-in

2 PCI to PCI bridges pass through addresses unchanged. Consequently, a PCI to PCI bridge node's implementation of
3 **map-out** typically just forwards the request to its parent.

4 For a master PCI bus node in "probe state", if the physical address is relocatable and there are no other active
5 mappings within the relocatable region containing that address, the **map-out** method shall unassign the base
6 address of the region, freeing the corresponding range of PCI address space for later re-use. A Standard FCode
7 program shall unmap (as with **map-out**) all base addresses that it mapped and shall siable memory or I/O space
8 access in the Command Register.

9 **dma-alloc**   (size -- virt)   Allocate a memory region for later use

10 **dma-free**   (virt size --)   Free memory allocated with dma-alloc

11 **dma-map-in**   (.. virt size cacheable? -- devaddr)   Convert virtual address to device bus DMA address.

12 **dma-map-out**   (virt devaddr size --)   Free DMA mapping set up with dma-map-in

13 **dma-sync**   (virt devaddr size --)   Synchronize (flush) DMA memory caches

14 **probe-self** (arg-str arg-len reg-str reg-len fcode-str fcode-len --)   Interpret FCode, as a child of this node

15 **decode-unit** (addr len -- phys.lo phys.mid phys.hi)   Convert text representation of address to numerical representation

16 **encode-unit** (phys.lo phys.mid phys.hi -- addr len)   Convert numerical representation of address to text representation

17 *Note: The PCI bus is little-endian; i.e. a byte address whose least-significant two bits are both zero uses the bus*
18 *byte lane containing the least-significant portion of a 32-bit quantity. Typically, a bridge from a big-endian bus*
19 *to a PCI bus will swap the byte lanes so that the order of a sequence of bytes is preserved when that sequence is*
20 *transferred across the bridge. As a result, the hardware changes the position of bytes within a 32-bit quantity that*
21 *is viewed as a 32-bit unit, rather than as a sequence of individually-addressed bytes. In order to properly*
22 *implement the semantics of the Open Firmware register access words (e.g. **rl!**), the device node for such byte-*
23 *swapping bridges must substitute versions of those words that "undo" the hardware byte-swapping.*

24 Bus-specific Methods for Bus Nodes

25 Configuration Access Words

26 The methods described below have execution semantics similar (especially with respect to write-buffer flushing,
27 atomicity, etc.) to those of the register access words (e.g., **rb@**, **rw!**); in most implementations, these
28 methods will be implemented via the register access words.

29 The data type 'config-addr' refers to the 'phys.hi' cell of the numerical representation of a Configuration Space
30 address. The 'config-addr' shall be aligned to the data type of the access.

31 **config-l@**   (config-addr -- data)
32
33   Performs a 32-bit Configuration Read.

34 **config-l!**   (data config-addr --)
35
36   Performs a 32-bit Configuration Write.

37 **config-w@**   (config-addr -- data)
38
39   Performs a 16-bit Configuration Read.

40 **config-w!**   (data config-addr --)
41
42   Performs a 16-bit Configuration Write.

43 **config-b@**   (config-addr -- data)
44
45   Performs an 8-bit Configuration Read.

46 **config-b!**   (data config-addr --)
47   Performs an 8-bit Configuration Write.

48 **assign-package-addresses**   (phandle --)
49   Assigns addresses (i.e., creates `"assigned-addresses"` property) for the child node denoted by *phandle*.
50

51 Address-less Access Words

52 **intr-ack**   (--)
53   Performs a PCI Interrupt Acknowledge Cycle.
54

1   **special-!**   (data bus# --)
2   Performs a PCI Special Cycle on the indicated bus#.

3   *Note: Standard PCI to PCI bridges provide a mechanism for converting Configuration Cycles with particular*
4   *addresses to Special Cycles. Consequently, for a PCI to PCI bridge, the likely implementation of* **special-!**
5   *involves invoking the parent node's* **config-l!** *method.*
6

7   **Child Nodes**

8   *Note: A PCI to PCI bridge is a parent of one PCI bus and a child of another. Consequently, a device node*
9   *representing a PCI bridge is both a Bus Node and a Child Node, with both sets of properties and methods.*

10   **Properties**

11   **Open Firmware-defined Properties for Child Nodes**

12   The following properties, as defined in Open Firmware, have special meanings or interpretations for PCI.

13   **"reg"**   S
14   Standard *prop-name*, defines device's addressable regions.
15   *prop-encoded-array*: Arbitrary number of (*phys-addr size*) pairs.
16   *phys-addr* is (*phys.lo phys.mid phys.hi*), encoded as with **encode-phys**. *size* is a pair of integers, each encoded
17   as with **encode-int** .
18   The first integer denotes the most-significant 32 bits of the 64-bit region size, and the second integer denotes the
19   least significant 32 bits thereof.
20   This property is mandatory for PCI Child Nodes, as defined by Open Firmware. The property value consists of a
21   sequence of (*phys-addr, size*) pairs. In the first such pair, the *phys-addr* component shall be the Configuration
22   Space address of the beginning of the function's set of configuration registers (i.e. the rrrrrrrr field is zero) and the
23   *size* component shall be zero. Each additional (*phys-addr, size*) pair shall specify the address of an addressable
24   region of Memory Space or I/O Space associated with the function.
25   In the event that a function has an addressable region that can be accessed relative to more than one Base Address
26   Register (for example, in Memory Space relative to one Base Register, and in I/O Space relative to another), only
27   the primary access path (typically, the one in Memory Space) shall be listed in the **"reg"** property, and the
28   secondary access path shall be listed in the **"alternate-reg"** property.
29

30   **"interrupts"**   S
31   *prop-name*, the presence of which indicates that the function represented by this node is connected to a PCI
32   expansion connector's interrupt line.
33   *prop-encoded-array*: Integer, encoded as with **encode-int**. The integer represents the interrupt line to which
34   this function's interrupt is connected; INTA=1, INTB=2, INTC=3, INTD=4. This value is determined from the
35   contents of the device's Configuration Interrupt Pin Register.
36

37   **Bus-specific Properties for Child Nodes**

38   Standard Packages corresponding to devices that are children of a PCI bus shall implement the following
39   properties, if applicable.

40

41   **"alternate-reg"**   S
42   *prop-name*, defines alternate access paths for addressable regions.
43   *prop-encoded-array*: Arbitrary number of (*phys-addr size*) pairs.
44   *phys-addr* is (*phys.lo phys.mid phys.hi*), encoded as with **encode-phys.** *size* is a pair of integers, each
45   encoded as with **encode-int** .
46   The first integer denotes the most-significant 32 bits of the 64-bit region size, and the second integer denotes the
47   least significant 32 bits thereof.
48   This property describes alternative access paths for the addressable regions described by the **"reg"** property.
49   Typically, an alternative access path exists when a particular part of a device can be accessed either in Memory
50   Space or in I/O Space, with a separate Base Address register for each of the two access paths. The primary access
51   paths are described by the **"reg"** property, and the secondary access paths, if any, are described by the
52   **"alternate-reg"** property.
53   If the function has no alternative access paths, the device node shall have no **"alternate-reg"** property. If
54   the device has alternative access paths, each entry (i.e. each *phys-addr size* pair) of its value represents the
55   secondary access path for the addressable region whose primary access path is in the corresponding entry of the
56   **"reg"** property value. If the number of **"alternate-reg"** entries exceeds the number of **"reg"** property
57   entries, the additional entries denote addressable regions that are not represented by **"reg"** property entries, and

1   are thus not intended to be used in normal operation; such regions might, for example, be used for diagnostic
2   functions. If the number of **"alternate-reg"** entries is less than the number of **"reg"** entries, the regions
3   described by the extra **"reg"** entries do not have alternative access paths. An **"alternate-reg"** entry
4   whose *phys.hi* component is zero indicates that the corresponding region does not have an alternative access path;
5   such an entry can be used as a "place holder" to preserve the positions of later entries relative to the corresponding
6   **"reg"** entries. The first **"alternate-reg"** entry, corresponding to the **"reg"** entry describing the
7   function's Configuration Space registers, shall have a *phys.hi* component of zero.

9 **"fcode-rom-offset"**							S

10 *prop-name*, denotes offset of FCode image within the device's Expansion ROM.

11 *prop-encode-arrray*: one integer, encoded as with **encode-int**.

12 This property indicates the offset of the PCI Expansion ROM image within the device's Expansion ROM in which
13 the FCode image was found; i.e., the offset of the 0xAA55 signature of that image's PCI Expansion ROM Header.
14 This value *shall* be generated before the FCode is evaluated. Note that the absence of this property indicates that
15 no FCode exists for this device node.

17 **"assigned-addresses"**							S

18 *prop-name*, denotes assigned physical addresses

19 *prop-encoded-array*: Zero to six (*phys-addr size*) pairs.

20 *phys-addr* is (*phys.lo phys.mid phys.hi*), encoded as with **encode-phys**. *size* is a pair of integers, each encoded
21 as with **encode-int** .

22 The first integer denotes the most-significant 32 bits of the 64-bit region size, and the second integer denotes the
23 least significant 32 bits thereof.

24 Each entry (i.e. each *phys-addr size* pair) in this property value corresponds to either one or two (in the case 64-
25 bit-address Memory Space) of the function's Configuration Space base address registers. The entry indicates the
26 physical address that has been assigned to that base address register, and the size in bytes of the assigned region.
27 The size shall be a power of two (since the structure of PCI Base Address registers forces the decoding granularity to
28 powers of two). The 'n' bit of each *phys-addr* shall be set to 1, indicating that the address is absolute (within the
29 PCI domain's address space), not relative to the start of a relocatable region. The type code shall not be '00'
30 (Configuration Space). The 'bbbbbbbb,ddddd,fff,rrrrrrrr' field indicates the base register to which the
31 entry applies, and the 'hh..hh,ll..ll' field contains the assigned address.

32 If addresses have not yet been assigned to the function's relocatable regions, this property shall be absent.

33 The values reported in **"assigned-addresses"** represent the physical addresses that have been assigned. If
34 Open Firmware can not assign address space for a resource (e.g., the address space has been exhausted), that
35 resourcs will not have an entry in the **"assigned-addresses"** property. If no resources were assigned
36 address space, the **"assigned-addresses"** property *shall* have a *prop-encoded-array* of zero length.

37 *Note: There is no implied correspondence between the order of entries in the* **"reg"** *property value and order of*
38 *entries in the* **"assigned-addresses"** *property value. The correspondence between the* **"reg"** *entries and*
39 **"assigned-addresses"** *entries is determined by matching the fields denoting the Base Address register.*

41 **"power-consumption"**							S

42 *prop-name*, describes function's power requirements

43 *prop-encoded-array*: list of integers, encoded as with **encode-int**, describing the device's maximum power
44 consumption in microwatts, categorized by the various power rails and the device's power-management state
45 (standby or fully-on). The ints are encoded in the following order:

46   unspecified standby, unspecified full-on, +5V standby, +5V full-on, +3.3V standby, +3.3V full-on, I/O pwr
47   standby, I/O pwr full-on, reserved standby, reserved full-on

48 The "unspecified" entries indicate that the power division among the various rails is unknown. The "unspecified"
49 entries shall be zero if any of the other entries are non-zero. The "unspecified" entries are provided so that the
50 **"power-consumption"** property can be created for devices without FCode, from the information on the
51 PRSNT1# and PRSNT2# connector pins.

52 If the number of ints in the encoded property value is less than ten, the power consumption is zero for the cases
53 corresponding to the missing entries. For example, if there are four ints, they correspond to the two "unspecified"
54 and the two "+5" numbers, and the others are zero.

56 **Standard PCI Configuration Properties**

57 The following properties are created during the probing process, after the device node has been created, but before
58 evaluating the device's FCode (if any). They represent the values of standard PCI configuration registers. This
59 information is likely to be useful for Client and User interfaces.

60 Unless specified otherwise, each of the following properties has a *prop-encoded-array* whose value is an integer
61 taken directly from the corresponding hardware register, encoded as with **encode-int**.

62 **"vendor-id"**								S
63 **"device-id"**								S
64 **"revision-id"**								S
65 **"class-code"**								S

1 **"interrupts"** S
2   This property shall be present if the Interrupt Pin register is non-zero, and shall be absent otherwise.
3 **"min-grant"** S
4 **"max-latency"** S
5 **"devsel-speed"** S
6 **"fast-back-to-back"** S
7   *prop-encoded-array*: <none>
8   This property shall be present if the "Fast Back-to-Back" bit (bit 7) in the function's Status Register is set, and
9   shall be absent otherwise.
10 **"subsystem-id"**
11   This property shall be present if the "Subsystem ID" register is non-zero, and shall be absent otherwise.
12 **"subsystem-vendor-id"**
13   This property shall be present if the "Subsystem Vendor ID" register is non-zero, and shall be absent otherwise.
14 **"66mhz-capable"**
15   *prop-encoded-array*: <none>
16   This property shall be present if the "66 MHz Capable" bit (bit 6) in the function's Status Register is set, and shall
17   be absent otherwise.
18 **"udf-supported"**
19   *prop-encoded-array*: <none>
20   This property shall be present if the "UDF Supported" bit (bit 5) in the function's Status Register is set, and shall
21   be absent otherwise.

22
23

24 **Methods**

25 **Bus-specific User Interface Commands**

26 An Open Firmware-compliant User Interface on a system with PCI *should* implement the following PCI-specific
27 user interface commands.

28 **probe-pci** (--)
29   Interprets FCode for all built-in PCI slots in numerical order.
30   Enter "probe state", thus affecting subsequent behavior of the **map-in** and **map-out** methods.
31   Scan all slots in numerical order. For each slot, read the header type field in the configuration register set for
32   function number 0. If the header type field indicates a PCI-PCI bridge, perform the function described in the
33   Probing PCI-PCI bridges section. If the header type field indicates a multi-function device, perform the following
34   sequence for each of the functions that are present (as determined by the presence of a non-FFFFh value in the
35   Vendor ID field of the function's Configuration Space header). Otherwise, perform the following sequence for the
36   card's function number 0. The first attempted access to each function *shall* use **lpeek**, because in some systems
37   an attempted access to a non-existent device might result in a processor exception (e.g. a "bus error").
38   *Note: Although some PCI implementations will not generate processor exceptions for aborted cycles, that is not*
39   *an inherent limitation of PCI itself, but instead an implementation choice that is appropriate for some system*
40   *architectures. A PCI host bridge knows if it terminated a cycle with a master abort. Since the PC system*
41   *architecture lacks the notion of a bus error, PC to PCI host bridges cannot report a bus error to the PC, so they have*
42   *to complete the cycle and return all ones to the x86 processor. However, in a non-PC system, the PCI host bridge*
43   *could terminate the processor cycle with a bus error. Open Firmware **peek** and **poke** can behave in their normal*
44   *way; if the processor can get a bus error, peek and poke can report it. If not, **peek** and **poke** will never say they*
45   *got a bus error, they will just return whatever data the cycle yielded. This is not a problem, because the probing*
46   *process involves doing a **peek** and also looking at the data to see if it is right.*
47   Create the following properties from the information given in the configuration space header.
48   **"vendor-id"**
49   **"device-id"**
50   **"revision-id"**
51   **"class-code"**
52   **"interrupts"**
53   **"min-grant"** (Unless Header Type is 01h)
54   **"max-latency"** (Unless Header Type is 01h)
55   **"devsel-speed"**
56   **"fast-back-to-back"**
57   **"subsystem-id"**
58   **"subsystem-vendor-id"**
59   **"66mhz-capable"**

`"udf-supported"`

Note: The feasibility of automatically creating the above properties depends on the ability to recognize the configuration header format. At present, there are two such formats - the base format defined by the PCI Local Bus Specification *and the PCI to PCI bridge format defined by the* PCI to PCI Bridge Architecture Specification. *Those two formats are almost, but not entirely, consistent with respect to the fields defined above (in particular, the max-latency and min-grant fields have a different meaning in the bridge header format). If additional formats are defined in the future, then it is possible that firmware written before those formats are defined will not be able to recognize them. The question arises: Should the firmware assume that, with respect to the above fields, new formats are consistent with the existing ones, creating the properties without regard to header type, or should the firmware do nothing if it sees an unrecognized header type. The latter is, in some sense, safer, but it also precludes forwards compatibility, which is a serious deficiency.*

Then determine whether or not the function has a expansion ROM image containing an FCode Program.

Note: The location of the Expansion ROM Base Address Register differs between the two currently-defined header types. Where will it be in future header types? Furthermore, the details of Expansion ROMs on PCI to PCI bridges are not specified by the current revision of the PCI to PCI bridge spec.

If the function has an FCode Program, evaluate the FCode Program as follows:

Copy the FCode program from expansion ROM into a temporary buffer in RAM and evaluate it as with **`byte-load`**. (The temporary RAM buffer may be deallocated afterwards.) Set the **`"fcode-rom-offset"`** property to the offset of the ROM image at which the FCode was found.

When the FCode Program begins execution, **`my-address`** and **`my-space`** together return the Configuration Space address of the device's configuration register set.

Note: Since the phys.mid and phys.lo components of Configuration Spaces addresses must be zero, **`my-address`** *returns a pair of zeros; the interesting phys.hi information, which is necessary for accessing the configuration registers via the* **`config-xx`** *methods, is returned by* **`my-space`**.

The FCode Program is responsible for creating the **`"name"`** and **`"reg"`** properties.

If the function does not have an FCode Program:

Create the following properties from information in the device's Configuration Space registers:

`"reg"` Create entries for all active configuration base address registers, including the Expansion ROM base register, with size components describing the total size of the region mapped by each register. (Without FCode, it is not necessarily possible to determine whether or not there are multiple base address registers mapping the same resource, so it is not possible to create an **`"alternate-reg"`** property.)

Note: the number of active base address registers depends in part on the header type configuration field; in particular, header types 0x01and 0x81, denoting the standard PCI to PCI bridge header format, have at most two base address registers, whereas header types 0x00 and 0x80have up to seven base address registers (including the Expansion ROM's).

`"name"`   Construct a name of the form **`pciVVVV,DDDD`**. If the Subsystem ID field in the configuration registers for this device is non-zero, VVVV,DDDD *shall* be the Subsystem Vendor ID and Subsystem ID respectively; otherwise VVVV,DDDD *shall* be the value of the Vendor ID and Device ID fields. VVVV and DDDD are ASCII hexadecimal numbers, lower case, without leading zeros.

Create the **`"power-consumption"`** property from the state of the PRSNT1# and PRSNT2# connector, if possible.

Disable fixed-address response by clearing the Command Register.

After all slots have been so probed, exit "probe state", assign base addresses (by allocating the address space and setting the base address register) for each distinct base address register (or register pair) listed in any child's **`"reg"`** property, and create **`"assigned-addresses"`** properties describing those assignments in the corresponding child device nodes.

On each PCI bus within the domain, set the Latency Timer registers for each master to values appropriate for the other devices on that bus, according to the values of the other device's MIN_GNT and MAX_LAT registers.

On each PCI bus within the domain, if all target devices on that bus have "fast back-to-back" capability, set the "fast back-to-back" enable bits in the Command registers of master devices.

make-properties   (--)

Create the default PCI properties (as described above for **probe-pci**) for the *current instance*.

This user interface word is intended to be used for debugging FCode within the context of **begin-package** … **end-package**. This word *should* be exectuted before evaluating the FCode for the node.

assign-addresses

Assign addresses for the *current instance*.

This user interface word is intended to be used for debugging Fcode within the context of **begin-package** … **end-pacakge**. Executing this word causes addresses to be assigned to this node (based on the current **"reg"** property value), creating an **"assigned-addresses"** property replecting those addresses. This word should be executed after evaluating the FCode for the node.

Probing PCI-PCI bridges

The recursive algorithm described in this section allows bus number and address assignment to be done in a single depth-first manner. Bus numbers are assigned on the way down the PCI bus heirarchy and addresses are assigned to on the way back up. Another algorithm may be used.

Note: while this is a simple algorithm (e.g., it does not require a "global" address allocation pass), it does not provide the most optimal system-wide address assignment.

If the function is a standard PCI-PCI bridge (as indicated by the class code and the header type fields), set the bridge's Primary Bus # register to the bus number of the parent bus, assign the next bus number to that bridge, setting its Secondary Bus # register to that number, set the bridge's Subordinate Bus # register to `0xFF`, and recursively scan the slots of that bridge's subordinate bus.

When that recursive scanning process returns, set the bridge's Subordinate Bus # register to the largest bus number assigned during the recursive scan. At this point, bus numbers have been assigned to all subordinate buses, and addresses have been assigned for all devices on the subordnate buses, for this bridge within the PCI domain. Then, assign addresses to all devices on the Secondary Bus and set the Memory Base, Memory Limit, I/O Base and I/O Limit registers of the bridge to their appropriate values and enable Memory and I/O transactions. Due to the mapping characteristics of PCI-PCI bridges, the ranges of Memory addresses for subordinate devices *shall* be aligned to 1 MB boundaries, and the ranges of I/O addresses *shall* be aligned to 4 KB boundaries.

Legacy devices

"Legacy" VGA and IDE devices that are implemented on PCI will typically have the same "hard-decoded" addresses as they did on ISA. Such devices that have FCode can use explicit indication of their address requirements as described above. However, for cards that have no FCode image, Open Firmware *shall* assume the standard address ranges and *shall* create the **"reg"** property with these ranges, in addition to any relocatable regions that have base registers.

For VGA devices (class-code = `0x000100` or `0x030000`), the address ranges are:

    0x3B0-0x3BB   (I/O, aliased; t=1)
    0x3C0-0x3DF   (I/O, aliased; t=1)
    0xA0000-0xBFFFF   (Memory, below 1MB, t=1)

For IDE devices (class-code = `0x010100`), the address ranges are:

    0x1F0-0x1F7   Primary Command Block (I/O)
    0x3F6   Primary Control Block (I/O)
    0x170-0x17F   Secondary Command Block (I/O)
    0x376   Secondary Control Block (I/O)

ROM Image Format for FCode:

Offset from start of ROM Image	Data
`00h – 01h`	ROM signature field of ROM Header (PCI spec 6.3.1.1)
`02h – 03h`	Pointer to FCode program. This is a 16-bit field that is the offset from the start of the ROM image and points to the FCode Program. The field is in little-endian format. (This field is within the "Reserved for processor-unique data" field of the ROM Header.)
`04h – 17h`	Reserved (remainder of "Reserved for processor-unique data" field of the ROM Header).
`18h – 19h`	"Pointer to PCI Data Structure" field of ROM Header.
`1Ah – FFFFh`	PCI Data Structure (PCI spec 6.3.1.2) with "Code Type" = 1
`38h – FFFFh`	The PCI Data Structure (PCI spec 6.3.1.2), Vital Product Data, and FCode Program can each begin anywhere within this range, in any order. The "Code Type" field of the PCI Data Structure shall have the value "1".
	The FCode Program is as described in Open Firmware; its size is given by the standard Open Firmware FCode Program header. FCode bytes shall appear at consecutive byte addresses.

Encapsulated Drivers

This section describes a mechanism which allows the encapsulation of run-time drivers within the standard Open Firmware expansion ROM.

The FCode contained within a PCI card's expansion ROM provides for Open Firmware drivers for the device. To enhance the "plug-and-play" of cards in common system platforms, it is desirable to be able to include run-time drivers within this expansion ROM, thus eliminating the extra step of installing drivers onto the OS boot device.

The information about run-time drivers is encoded as additional standard properties within the device tree. These properties are created by the FCode probe code of the plug-in card, and are used by the OS to locate and load the appropriate driver. Two new properties are defined; they differ as to how the location of the run-time driver is defined.

`"driver,…"` format

This property, encoded as with **`encode-bytes`**, contains the run-time driver.

This format is used when the run-time driver is contained within the FCode image, itself. The value of the property is the encapsulated driver; the `prop-addr`, `prop-len` reported by the various "get-property" FCodes and/or `getprop` Client interface call represent the location and size of the driver within the device tree's data space. I.e., **`decode-bytes`** could be used to copy the driver into the desired run-time location.

`"driver-reg,…"` format

This property, encoded as with the **`"reg"`** standard property , contains a relative pointer to the run-time driver.

This format is used when the driver is not directly contained within the FCode image, but rather, is located in some other portion of the Expansion ROM. The value is encoded in a **`"reg"`** format, where the address is relative to the expansion ROM's base address. This format conserves device tree (and, FCode) space, but requires the OS to perform the actions of mapping in the Expansion ROM, using the information supplied by this property and the **`"assigned-addresses"`** for the Expansion ROM, and copying the driver, itself.

*Note: the **`"fcode-rom-offset"`** property facilitates the generation of this property within the context of the FCode's image. The driver can be located relative to the ROM image that contains the FCode (but, does not have to be within the FCode, itself) without regard to the location of that ROM image relative to others within the same Expansion ROM. I.e., "self-relocating" images containing encapsualted drivers can be created that can be concatentated with other images without altering any data within an image (except, of course, for the Indicator to properly indicate the last image).*

1   **Naming conventions**

2   The complete property name for these encapsulated drivers is chosen to allow multiple drivers to co-exist within
3   the expansion ROM. An OS will locate its desired driver by an exact match of its property name among any
4   such `"driver,"` (`"driver-reg,"`) properties contained within the device tree for this device. The formats
5   of the complete names are:

6   `"driver,`*`OS-vendor`*`,`*`OS-type`*`,`*`Instruction-set`*`"`
7   `"driver-reg,`*`OS-vendor`*`,`*`OS-type`*`,`*`Instruction-set`*`"`

8   The OS-vendor component is as defined for device-names; i.e., organizational unique identifier (e.g., stock
9   symbol). The OS-type & Instruction-set components are defined by the OS-vendor. An example would be:

10   `"driver-reg,AAPL,MacOS,PowerPC"`

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