Ganglia Mark 2: A Dynamic Message Routing Surface

This paper describes a means for exchanging message transactions between nodes that do not share a common COM port using message frames whose headers hold source routing information that is updated incrementally as the frame moves between contiguous nodes that have been programmed to serve as part of a surface, or fabric, for this purpose. In the polyFORTH system, for example, all otherwise fallow nodes are programmed in this way and are utilized for most communications between the polyFORTH virtual machine and other interfaces elsewhere on the chip.

Each transaction with a target node consists of delivering to one of its ports a focusing call instruction word followed by one or more words of arbitrary payload, and receiving one or more words of arbitrary reply. Transactions begin by feeding a Ganglion frame from a source node outside the surface into the first Ganglion node from which it propagates along a path defined in that frame’s header. In this paper the Snorkel is used as an example of a source node.

The Mark 2 protocol supports any necessary routing path and is suitable for debugging and other ad hoc communications in single or multi-chip environments, yet still fits in the upper half of node RAM. This version is incorporated in and used by polyFORTH starting with level 02c. In addition the various caveats of Mark 1 have been eliminated and the messages are easier to generate automatically.

Related Documents
AN003: SRAM Control Cluster Mark 1
AN010: Snorkel Mark 1
DB006: polyFORTH Supplement for G144A12
Many additional applications such as AN001, AN008 and AN012 utilize this mechanism.

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1. Problem Statement

Within a node cluster static data routing is the fastest and simplest way for nodes to communicate with one another. Between clusters, though, there are times when dynamic message routing is needed. For example, in many cases functions cluster around relevant I/O pins located at the edges of the chip. Data flow may be episodic rather than continuous. In such cases generalized traffic control at path crossings can be expensive of energy and code. The compelling motivation in this case was the need for high-level polyFORTH software to communicate with any relevant I/O nodes, such as SPI flash, using dynamic routing controlled and defined directly by the high-level software and tailored for the application. A second purpose is to support richer routing capability in the second-generation IDE.

2. Our Solution

This is a method of dynamic routing based upon a source-routed message frame. It depends on pre-programming all otherwise unused nodes called Ganglia with a program to interpret and process those frames incrementally, resulting in a communications fabric we call a surface of Ganglia. The message format is called a Ganglion frame, and the act of performing the actions prescribed by such a frame is a Ganglion transaction. The Mark 2 alleviates Mark 1 limitations and caveats while enabling new capabilities such as multi-chip IDE operations.

Each Ganglion Transaction consists of delivering one or more words of payload from a source node to a target node and receiving one or more words of reply, using a rectilinear routing path with as many segments as the circumstances require. When the payload is delivered to the target node it is preceded automatically by a focusing call to the port through which the rest of the payload is delivered and the reply received. No assumptions are made about software in the target node; even the focusing call does not necessarily imply that the target is executing the port being used. The Ganglion frame is structured as follows, with a header of 5 or more words and variable length payload/reply:

<table>
<thead>
<tr>
<th>18-bit word</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focusing call (updated for each port crossing)</td>
<td>First word of header, also included in payload delivery</td>
</tr>
<tr>
<td>call to pump routine in ganglia</td>
<td>Remaining header (≥4 words), not delivered to target</td>
</tr>
<tr>
<td>reply count, Y-1</td>
<td>- Focusing call (above) and path updated at each step</td>
</tr>
<tr>
<td>payload count, X-1</td>
<td>- Header stripped when delivering payload at destination</td>
</tr>
<tr>
<td>One or more words of path remaining. Each word defines a segment.</td>
<td>- Direction codes (d) are 0,1,2,3 are cardinal E,W,N,S.</td>
</tr>
<tr>
<td>e- ---- nnnn nnnn nnnd</td>
<td>- Distance (n) 1-relative. Nonzero means decrement (n) and take a step in direction (d). 0 means deliver in direction (d) if and only if (e) set marking this as the last segment; otherwise the segment is deleted and the next processed.</td>
</tr>
<tr>
<td>Payload (X words)</td>
<td>Sent with outbound frame and delivered after focusing call at destination</td>
</tr>
<tr>
<td>Reply (Y words)</td>
<td>Transferred from destination back to originator</td>
</tr>
</tbody>
</table>

A Ganglion transaction propagates outward from the Snorkel through a sequence of Ganglia along its path. Transactions are driven by the Snorkel Mark 1 between external SRAM and any port on the Snorkel node that connects to the surface of Ganglia, although nodes running other software may drive transactions if this creates no irresolvable routing problems. Each Ganglion interprets and updates the header to determine what node is next. That node is passed the focusing call and, if it is not the target node, the updated header follows. This is followed by the payload, after which the Ganglion waits to receive the reply, transferring it backward along the path. When each Ganglion has finished passing the reply, that node returns to warm (or whatever other execution address it may have been given before the transaction began) so it's ready for any port executable stimulus, including another Ganglion transaction.

The path segments are interpreted sequentially, as taking n steps in cardinal direction d. Steps are numbered from the first node seeing the message, typically the first node outside a snorkel. When all segments have been processed, delivery occurs to the next node in the most recent direction. A segment with initial n zero denotes a change of direction (for delivery if e set) without taking a step. Zero segment without e is effectively a no-op.
3. Implementation

The program loaded into the upper half of RAM in each Ganglion is generated using the following template after a table has been generated at location x20 giving call instructions for the ports leading in the cardinal directions used by the encoded routing. This table is used to compensate for the pattern of node orientations.

| 0 Background nodes are filled by default with ganglia; routing code is in x20..x3F thus they may support other messaging methods such as IDE or "neural" as well until node has been programmed in some other way. |
| 1 Routing directions are geographic East-West-North-South. Each node has a table "ews" that translates these directions sequentially from the first word transmitted into port addresses. |
| 2 Four bins hold node orientations: |
| 3 This block assembles the four of these bins, differing only in their own tables. |

| 0 (MK2 Ganglia) ASM |
| 1 | 2 : aim (pth - pth a) dup 3. and # ews SxS lit xor b! |
| 2 | @ dup b! (focus) b! b! (pump) leap |
| 3 | 5 : whither (pth) .4. .aim (pump call) !b |
| 4 | 6 (cnts) r> !b r> !b .. |
| 5 | 7 (path) ahead begin drop @ swap then dup !b until |
| 6 | 8 : payload begin @ !b unext begin @ !b unext ; |
| 7 | 9 : pump then r> a! (cnts) @ dup @ dup @ dup @ dup @ dup |
| 8 | 10 : turn begin @ dup xFF, and if (next leg) drop whither; |
| 9 | 11 : then drop until (deliver) aim r> r> payload |
| 10 | 12 : aim r> r> payload |
| 11 | 13 |
| 12 | 14 |
| 13 | 15 |

Or, the second block only as represented in colorForth:

```
141 list
  . ganglion mark 2,
  . 20 org r lud --- --1. ---u -d--
aim 24 p-pa dup 3 and # ews SxS lit xor b!
  . @ dup b! (focus) b! b! (pump) leap
  . 5 : whither (pth) .4. .aim (pump call) !b
  . 6 (cnts) r> !b r> !b ..
  . 7 (path) ahead begin drop @ swap then dup !b until
  . 8 : payload begin @ !b unext begin @ !b unext ;
  . 9 : pump then r> a! (cnts) @ dup @ dup @ dup @ dup @ dup @ dup |
  . 10 : turn begin @ dup xFF, and if (next leg) drop whither;
  . 11 : then drop until (deliver) aim r> r> payload |
  . 12 : aim r> r> payload |
  . 13 |
  . 14 |
  . 15 |
```

Path encoding is interpreted sequentially from the first word transmitted, with **d** specifying cardinal direction (0 right or East, 1 left or West, 2 up or North, 3 down or South) and **n** specifying a number of steps to be taken in that direction. Counting begins from the first Ganglion, not from the Snorkel. If a second segment is needed, it is encoded in the next word and so on. Unused segments are not included in the message, and the final segment is marked with its sign bit.
The path is interpreted in each Ganglion, selecting a port based on cardinal directions and either passing a Ganglion frame to the next Ganglion or delivering a payload to the target node when the path has been exhausted. The target node is given a focusing call at the beginning, in case the payload is port executable; whether the payload is code or data depends on what the target has been programmed to expect. Reply is passed backward through the port from which the message was received, after which the ganglion returns to whatever address received the initial focusing call. Normally Ganglia start at warm and so normally this return will be to the node's idle multiport execution address.

Each Ganglion is completely devoted to the processing of a message from the time it receives the focusing call at the start of a message until it has successfully written the last word of reply through the port from which it received the frame. The chain of Ganglia actively processing a transaction is an impenetrable wall while this is going on. Although it is possible for multiple paths such as ganglion messages and/or IDE wires to be active in a chip concurrently, only one of them may pass through a given node at a given time and the normal mechanism in a Ganglion cannot resolve multiple incoming focusing calls that are capable of occurring within an instruction time of each other. When multiple paths cross only once and this timing constraint is observed, traffic control is automatic. When such paths cross more than once, deadlock becomes possible so system design must ensure that does not happen.

Nothing precludes building special "plumbing fixtures" to facilitate traffic control. A node may be programmed to resolve effectively simultaneous arrival of focusing calls by polling io and selecting which port to process. It's also possible to program a node for acting as a transparent bridge with predefined output port for each input port, thus permitting two active paths of any sort to cross. The cost of such polling, in the F18A, is the power bill for a node running at 100% duty cycle.
4. Usage Examples

All examples shown here use polyFORTH, but there is nothing to preclude your programming F18 nodes to drive their own transactions across a surface of Ganglia so long as path crossing rules are respected.

4.1 polyFORTH Mechanism

The outgoing part of a Ganglion frame is normally built in external SRAM as a sequence of double words so it can be transmitted as 18-bit data using the Snorkel. Block 28, below, defines the essential vocabulary, and block 31 gives a simple example of using this vocabulary.

The following words facilitate compilation of Ganglion frames with static paths:

- **:UP** :DOWN :RIGHT :LEFT**
  - Double precision values of port focusing call instructions
- **2 , ( d)** Compiles a double precision value into memory for 18-bit snorkel transfer
- **W , ( n)** Compiles a single precision value into memory for 18-bit snorkel transfer
- **+E +W +N +S all ( n)** Compiles a path segment to turn in the desired direction and step n nodes
- **deliv** Marks the last segment to deliver to the next node in the direction in which it turned.

The example in block 31 compiles a 14-word structure in polyFORTH memory that will generate a Ganglion frame of seven words as follows:

- **:DOWN 2 , Compiles a focusing call for the down port of the first Ganglion, node 307, next to the snorkel.**
- **1 , 2034 , Compiles a call instruction to pump in the Ganglion.**
- **1 W , Compiles reply count, meaning a 2-word reply is expected.**
- **0 W , Compiles payload count, meaning a 1-word payload follows.**
- **2 +N 8 +E deliv Compiles a path that goes upward 2 nodes from 307, to 507, then goes rightward eight nodes to node 515, after which payload is delivered rightward to target node 516 (see next page for more information on path definitions.)**
- **1 , 2200 , Compiles the payload: A call to location 0 in the target node with P9 set for Extended Arithmetic Mode. Thus the target node receives two words, the appropriate focusing call followed by this call to zero, and will return two words of reply through the same port.**
In the block diagram above, all white nodes have been loaded with Ganglion code and are suspended at their appropriate multiport execution addresses. The dashed lines show five Ganglion paths discussed here. In each case the Snorkel is directed to use its down port and Ganglion frames begin with down to focus node 307 on the Snorkel. In each case the path leads to the last Ganglion, denoted by colored circles, for delivery to the target node (arrow). The examples are color coded to match the graphical paths above.

2 +N 2 +W 1 +N deliv This path is used to communicate with code in node 705 that controls SPI operations such as the flash memory on the Evaluation Board. Delivery is in same direction as the last segment in the path (upward).

2 +N 8 +E deliv This is the path used in the example above from block 31 for communicating with the clock monitoring code in node 516. Note that the third segment is not used.

3 +N 9 +E 0 +S deliv This is an alternative path for communicating with node 516. In this example, the third segment is of zero length, causing the last Ganglion (node 616) to deliver downward. If this segment were written as zero, the delivery would be made rightwards to node 617.

0 +E deliv When the first segment is of zero length, it simply causes the first (and last) Ganglion to deliver in the given direction.

5 +W 1 +N 0 +E deliv This path was impossible in Mark 1. Delivers to node 403 through its right port as expected.

1 +N 7 +W 1 +S 1 +N 8 +E 0 +N deliv This path was impossible in Mark 1. The first two segments reach node 400. The third, 1 +S steps across the port bridge into node 10400 in the target chip if using the bridge and wired as on the evaluation board. The fourth steps up to row 10500, the next segment goes to node 10508, and we deliver upward from there into the target node (10608).
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