Architectural Implications of Brick and Mortar Silicon Manufacturing

Martha Mercaldi Kim
Mark Oskin
University of Washington

Mojtaba Mehrara
Todd Austin
University of Michigan
Cost of Production

- Standard Cell ASIC

Production Cost vs. Product Volume
Cost of Production

- Standard Cell ASIC
- FPGA

Product Volume

Production Cost

[www.edn.com]
Cost of Production

- Standard Cell ASIC
- FPGA
- Brick & Mortar Goal

Production Cost vs. Product Volume
Brick and Mortar Chips

1. Bricks
   - Mass-produced ASICs
   - Standard interface
   - Fixed set of functions
Brick and Mortar Chips

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   - Single, interconnect function
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3. Assembly
   - Alignment
     - e.g. robotics, fluidic
   - Bonding
     - e.g. flip-chip, proximity
Benefits of Brick and Mortar

- **Chip manufacture**: mask-free, fab-free, improved yields
- **Chip performance**: mostly ASIC
- **Chip design**: uses today’s SoC design flow
Why Should Architects Care?

• Good architecture essential for viability
  • Brick function and form-factor
  • Inter-brick interconnect design
Outline

• Brick and Mortar Chips
  • Definition
  • Potential
  • Architectural Questions

• Brick and Mortar Architecture
  • Bricks
  • Interconnect

• Brick and Mortar Assembly
  • Options
  • Interaction with architecture
Brick Form Factor

- Each brick...
  - is square
  - has 15% of area reserved for extra circuitry
  - has one surface covered with flipchip pads

flipchip pad: 
25 um pitch, 2.5 Gbps
Brick Architecture

<table>
<thead>
<tr>
<th>Function Description</th>
<th>Area (um²)</th>
<th>Max Freq. (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USB 1.1 Physical Layer</td>
<td>2,201</td>
<td>2941</td>
</tr>
<tr>
<td>JPEG Decoder</td>
<td>625,457</td>
<td>629</td>
</tr>
<tr>
<td>RISC Core + 256K Cache</td>
<td>3,111,025</td>
<td>1087</td>
</tr>
</tbody>
</table>
Multiple Brick Sizes

Functional Block

Interconnect Interface

Multiple Brick Sizes

.5 mm

1 mm

2 mm
## Brick Size Selection

<table>
<thead>
<tr>
<th>Function Description</th>
<th>Circuit</th>
<th>Freq. Range at Brick Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (um²)</td>
<td>Max Freq. (MHz)</td>
</tr>
<tr>
<td>256 K SRAM (single-ported)</td>
<td>2,729,344</td>
<td>2315</td>
</tr>
<tr>
<td>JPEG Decoder</td>
<td>625,457</td>
<td>629</td>
</tr>
<tr>
<td>VGA/LCD Controller</td>
<td>4,301</td>
<td>1219</td>
</tr>
</tbody>
</table>

- Smallest brick to fit circuit, unless bandwidth **severely** constrained
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Interconnect Dilemma

- **General purpose interconnect facilities**
  - Communication known at design time \(\rightarrow\) configurable wires
  - Dynamic communication \(\rightarrow\) packet-switched net
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Assembly Alternatives

- Alignment
  - Robotic
  - Self-Assembly
  - Martha + tweezers
  - ...

- Bonding
  - Flip-chip
  - Proximity
  - ...

Assembly Alternatives

- **Alignment**
  - Robotic $$$, but fast
  - Self-Assembly $, but slow
  - Martha + tweezers
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- **Bonding**
  - Flip-chip
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Assembly Alternatives

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  - Robotic: $$$, but fast
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- **Alignment**
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- **Bonding**
  - Flip-chip: medium-density, but more robust connection
  - Proximity: high-density
  - ...

...
Assembly Alternatives

• **Alignment**
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• **Bonding**
  - Flip-chip medium-density, but more robust connection
  - Proximity high-density
  - ...

Fluidic Self Assembly

- Template - brick communication via proximity communication
  - Brick type check, BIST, speed grade
- Polymer on template can grip or eject bricks
Alignment:
Fluidic Self Assembly

- Washington EE experimental system
Assembly Time v. Number of Bricks

- Statistical simulator driven by experimentally derived rates of assembly and disassembly
Assembly Time v. Number of Bricks

- 10 bricks: 75 seconds
- 20 bricks: 250 seconds

Design Size vs. Seconds / Chip
Assembly Time v. Kinds of Bricks

![Graph showing assembly time in seconds compared to the number of kinds of bricks.](image)
Assembly Time v. Kinds of Bricks

Seconds / Chip vs Number of Kinds of Bricks

- 25 bricks
- 16 bricks
- 9 bricks
- 4 bricks
- 1 bricks
Assembly Time v. Kinds of Bricks

Seconds / Chip vs. Number of Kinds of Bricks

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Assembly Time v. Kinds of Bricks

The chart illustrates the assembly time in seconds per chip as a function of the number of kinds of bricks. Different line colors represent different numbers of bricks:

- Red: 25 bricks
- Dark blue: 16 bricks
- Medium blue: 9 bricks
- Green: 4 bricks
- Yellow: 1 brick

The X-axis represents the number of kinds of bricks, while the Y-axis shows the seconds per chip. As the number of kinds of bricks increases, the assembly time also increases significantly.
Assembly Time v. Brick Arrangement Slack

Seconds / Chip

"Slack" in Brick Arrangement
Evaluating Slack: Design Size

![Graph showing evaluation of slack in design size]

- *25 bricks*
- *16 bricks*
- *9 bricks*
- *4 bricks*
- *1 brick*

Seconds per Chip vs "Slack" in Brick Arrangement
Evaluating Slack: Brick Kinds

![Graph showing the relationship between "Slack" in Brick Arrangement and Seconds/Chip for 1, 2, 3, 4, and 5 kinds of bricks.](graph.png)
Evaluating Slack: Brick Kinds
Assembly and Architecture

- **Architecture can assist assembly by**
  - Reducing the number of kinds of bricks
    - i.e., two brick kinds v. one slightly reconfigurable circuit
  - Accommodating variable assemblies
Conclusion

Brick and Mortar process offers ASIC-like chips without the masks and fabs

Architecture is crucial to meet the performance goals of the process

With low-cost assembly techniques, can meet the economic goal as well