# Table Of Contents

1. Introduction
   - Project Overview
   - SUPERCOP, XBX and Hardware
   - Presentation of Results

2. Benchmarking Results
   - Atmel ATmega1284P
   - Texas Instruments MSP430FG4618
   - Texas Instruments AR7 (quick overview)
   - Atmel AT91RM9200 (quick overview)
   - Intel XScale IXP420 (quick overview)
   - NXP LPC1114
   - Texas Instruments LM3S811
   - Texas Instruments DM3730 (quick overview)

3. Conclusion
   - XBX Team SHA-3 Choice
XBX: Benchmarking of 'small devices' that

- can execute compiled C code
- can't run a POSIX compliant operating system
- can't run a C compiler
- are often embedded in consumer electronics
XBX: an extension of SUPERCOP-eBASH

Small devices require a different approach to benchmarking:

- Binaries have to be created on another system
- Memory footprint is an important metric
- Standardized timing services are unavailable
SUPERCOP, XBX and Hardware

XBX aims to extend SUPERCOP while retaining the most important features:

- Same source code format, same output format
- Different compilers and compiler option combinations
- Benchmarking of different input data sizes

XBX adds some new features beyond the scope of SUPERCOP:

- Amount of RAM and ROM required by a hash implementation
- Ability to run NIST SHA-3 style KATs on small devices
- Future plans: Energy consumption measurement
In order to reach a clear and simple recommendation we followed a two-step approach.

The first step, on a per-platform basis, is to:

- Define if memory footprint or speed is most important\(^1\)
- Define if 256- or 512-bit hash results will usually be required\(^2\)
- Apply some human judgement to balance memory and speed requirements in case of close calls
- Find the top three candidates for the platform and rank them

In the second step the individual ranking results are aggregated into a single score per candidate and an overall ranking is reached.

\(^1\) The ARM Cortex-M3 based LM3S811 platform is considered two times, once with memory footprint and once with speed as most important criterion.

\(^2\) This doesn't matter for Skein, which is virtually the same at 256- and 512-bit
Presentation of Platform Diagrams

For every target platform the speed of the candidate hash implementations is measured as well as RAM and ROM consumption. RAM and ROM consumption are merged into an 'Area' metric.

- Colour coding as in SUPERCOP shoot-out diagrams
- Solid shapes and lines for 256-bit version, dashed for 512-bit
- Both axes are scaled base-2 logarithmic
- X-Axis: $Area = 4 \times RAM + ROM$, identical range for all platforms
- Y-Axis: Throughput in bytes per kilocycles
Benchmarking results and ranking of candidates per platform.
AVR (8-bit): Atmel ATmega1284P

- Best XBX platform for estimating smart card performance
- Memory footprint most important, focus on 256-bit hashes
- Detailed discussion of candidate ranking on next slide
AVR (8-bit): Atmel ATmega1284P Ranking

- **1st: Keccak**

Throughput [bytes/10^3 cycles]

Area [4^RAM Bytes + ROM Bytes]
AVR (8-bit): Atmel ATmega1284P Ranking

1st: Keccak
2nd: BLAKE

Throughput [bytes/10^3 cycles]
Area [4* RAM Bytes + ROM Bytes]
AVR (8-bit): Atmel ATmega1284P Ranking

- 1st: Keccak
- 2nd: BLAKE
- 3rd: Grøstl and Skein are tied
AVR (8-bit): Atmel ATmega1284P Ranking

- **1st**: Keccak
- **2nd**: BLAKE
- **3rd**: Grøstl and Skein are tied

![Graph showing throughput and area comparison for different hash functions](image-url)
MSP430 (16-bit): Texas Instruments MSP430FG4618

- Low power platform, setup developed at GMU
- Memory footprint most important, focus on 256-bit hashes
- Detailed discussion of candidate ranking on next slide

```
0.03125 0.0625 0.125 0.25 0.5 1 2 4
2048 4096 8192 16384 32768 65536

Throughput [bytes/10^3 cycles]

Area [4* RAM Bytes + ROM Bytes]

blake256
blake512
groestl256
groestl512
jh256
jh512
keccak512
keccak1024
skein512256
skein512512
sha256
sha512
```
MSP430 (16-bit): MSP430FG4618 Ranking

1st: Grøstl and BLAKE are tied
1st: Grøstl and BLAKE are tied
MSP430 (16-bit): MSP430FG4618 Ranking

- 1st: Grøstl and BLAKE are tied
- 3rd: Keccak
MIPS (32-bit): Texas Instruments AR7

- MIPS core, Linux based, popular in DSL routers
- Throughput most important, no output length focus
- 1st: BLAKE, 2nd: Skein, 3rd: Keccak

![Throughput vs Area Graph]

Throughput [bytes/10^3 cycles]

Area [4* RAM Bytes + ROM Bytes]
ARM 920T (32-bit): Atmel AT91RM9200

- Older ARM core, Linux based, popular in automation
- Throughput most important, no output length focus
- 1st: BLAKE, 2nd: Keccak and Skein tied
ARMv5TE (32-bit): Intel XScale IXP420

- Older ARM core, Linux based, popular in NAS appliances
- Throughput most important, no output length focus
- 1st: BLAKE, 2nd: Skein, 3rd: Grøstl

![Graph showing benchmarking results for various hash functions and their throughput vs. area comparison.](image-url)
ARM Cortex-M0 (32-bit): NXP LPC1114

- Current ARM core, low cost, used in microcontrollers
- Memory footprint most important but no output length focus
- Detailed discussion of candidate ranking on next slide
ARM Cortex-M0 (32-bit): NXP LPC1114 Ranking

1st: BLAKE
ARM Cortex-M0 (32-bit): NXP LPC1114 Ranking

1st: BLAKE
2nd: Keccak
1st: BLAKE
2nd: Keccak
3rd: Grøstl and JH are tied

Throughput [bytes/10^3 cycles]

Area [4* RAM Bytes + ROM Bytes]
ARM Cortex-M0 (32-bit): NXP LPC1114 Ranking

- 1st: BLAKE
- 2nd: Keccak
- 3rd: Grøstl and JH are tied
Current ARM core, cost-performance balanced, two criteria
- Low cost: memory footprint but no output length focus
- Speed: throughput, no output length focus
ARM Cortex-M3 (32-bit): TI LM3S811 Low Cost Ranking

1st: BLAKE
ARM Cortex-M3 (32-bit): TI LM3S811 Low Cost Ranking

- **1st**: BLAKE
- **2nd**: Skein and Grøstl are tied
ARM Cortex-M3 (32-bit): TI LM3S811 Low Cost Ranking

- 1st: BLAKE
- 2nd: Skein and Grøstl are tied
1st: BLAKE and Skein are tied
1st: BLAKE and Skein are tied
1st: BLAKE and Skein are tied
3rd: Keccak
ARM Cortex-A8 (32-bit + SIMD): TI DM3730

- Current ARM core with vector extensions, Linux based
- Throughput most important, no output length focus
- 1st: Skein, 2nd: BLAKE, 3rd: Keccak
Bringing it all together:

- Summarize data from 9 (8) platforms
- Three points for a first place
- Two points for a second place
- One for third
# XBX Team SHA-3 Choice

<table>
<thead>
<tr>
<th>SHA-3 Candidate</th>
<th>Ranked 1st (3 points)</th>
<th>Ranked 2nd (2 points)</th>
<th>Ranked 3rd (1 point)</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAKE</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Keccak</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Grøstl</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>JH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Skein</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

- **BLAKE** is our overall first choice, balanced for most platforms
<table>
<thead>
<tr>
<th>SHA-3 Candidate</th>
<th>Ranked 1st (3 points)</th>
<th>Ranked 2nd (2 points)</th>
<th>Ranked 3rd (1 point)</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAKE</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Keccak</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Grøstl</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>JH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Skein</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

- BLAKE is our overall first choice, balanced for most platforms
- Skein is our overall second choice, strong on fast platforms
## XBX Team SHA-3 Choice

<table>
<thead>
<tr>
<th>SHA-3 Candidate</th>
<th>Ranked 1st (3 points)</th>
<th>Ranked 2nd (2 points)</th>
<th>Ranked 3rd (1 point)</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAKE</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Keccak</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Grøstl</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>JH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Skein</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

- **BLAKE** is our overall first choice, balanced for most platforms
- **Skein** is our overall second choice, strong on fast platforms
- **Keccak** is our overall third choice, strong on very small platforms
### XBX Team SHA-3 Choice

<table>
<thead>
<tr>
<th>SHA-3 Candidate</th>
<th>Ranked 1st (3 points)</th>
<th>Ranked 2nd (2 points)</th>
<th>Ranked 3rd (1 point)</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAKE</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Keccak</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Grøstl</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>JH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Skein</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

- **BLAKE** is our overall first choice, balanced for most platforms.
- **Skein** is our overall second choice, strong on fast platforms.
- **Keccak** is our overall third choice, strong on very small platforms.

**Update:** Grøstl-256 AVR assembly implementation submitted on March 1st makes Grøstl the winner for the Atmel ATmega1284P platform. BLAKE, Skein and Keccak thus lose one score point each. This puts Grøstl in third position tied with Keccak in the overall ranking.
### XBX Team SHA-3 Choice Update

<table>
<thead>
<tr>
<th>SHA-3 Candidate</th>
<th>Ranked 1st (3 points)</th>
<th>Ranked 2nd (2 points)</th>
<th>Ranked 3rd (1 point)</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLAKE</td>
<td>7 (1)</td>
<td>2 (1)</td>
<td>0 (1)</td>
<td>25 (24)</td>
</tr>
<tr>
<td>Keccak</td>
<td>1 (0)</td>
<td>2 (3)</td>
<td>4</td>
<td>11 (10)</td>
</tr>
<tr>
<td>Grøstl</td>
<td>1 (2)</td>
<td>1</td>
<td>3</td>
<td>8 (10)</td>
</tr>
<tr>
<td>JH</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Skein</td>
<td>2</td>
<td>4</td>
<td>1 (0)</td>
<td>15 (14)</td>
</tr>
</tbody>
</table>

- **BLAKE** is our overall first choice, balanced for most platforms
- **Skein** is our overall second choice, strong on fast platforms
- **Keccak** and **Grøstl** are our overall third choice, strong on very small platforms

**Update:** Grøstl-256 AVR assembly implementation submitted on March 1st makes Grøstl the winner for the Atmel ATmega1284P platform. BLAKE, Skein and Keccak thus loose one score point each. This puts Grøstl in third position tied with Keccak in the overall ranking.