Al 50 aniversario de la Ley de Moore, la nanoelectrónica en una encrucijada

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Moore’s Law at 50: the end in sight?
Nanoelectronics: the brains of our information society
Integrated circuits
Interconnects
Transistors
Moore’s Law

“It’s not a law in any real respect. It was an observation and a projection.”

Gordon Moore, IEEE Spectrum 2015
Moore’s observation, 1965

- First planar transistor (1959)
- First commercial integrated circuit (1961)

2x/year

Moore, Electronics 1965
By 1975, the number of components per integrated circuit for minimum cost will be 65,000.
10 years later...

32,000 components/chip

2x/year

Moore, IEDM 1975
Moore’s revised prediction, 1975

1975 prediction:

“By the end of the decade, the new slope might approximate a doubling every two years”

2x/2 years or
>40%/year for 45 years!

Intel microprocessors

1971:
Intel 4004
2250 transistors

2014:
Intel Xeon Haswell-E5
5.6B transistors
After 50 years of Moore’s Law

- information
- energy
- transportation
- medicine
- manufacturing
- entertainment
What if Moore’s Law had stopped in 1990?

GPS handheld device circa 1990

Cell phone circa 1990
What if Moore’s Law had stopped in 1980?

Laptop computer circa 1981
What if Moore’s Law had stopped in 1970?

TV set, circa 1970

![Graph showing the number of transistors over time]

- Number of transistors
- Year of introduction
- ~2x/2 yrs
What if Moore’s Law had never happened?

Insulin pump circa 1960

“Personal calculator” circa 1960
How transistors work

MOSFET =
Metal-Oxide-Semiconductor
Field-Effect Transistor

Switch

Gate

Source
Substrate

Drain

gate length
A sense of scale
A sense of scale

- 2015 transistor
- 1971 transistor
- 1959 transistor
Smaller is Better!

MOSFET performance improves as size scales down:

Switching speed $\uparrow$

Energy consumption $\downarrow$
“Triple dividends” of Moore’s Law

- Cost
- Performance
- Energy

Wikipedia
Changing transistor architecture
Increasing chemical complexity

1970’s
Increasing chemical complexity

1980’s
Increasing chemical complexity

1990’s
Increasing chemical complexity

2000’s
Increasing manufacturing complexity
Moore’s Law is really about economics
3D System on Chip

Cadence
Hynix
Effective parallel computing

4K-by-4K Matrix Multiplication benchmark on state-of-the-art Intel processor:

```python
for i in xrange(n):
    for j in xrange(n):
        for k in xrange(n):
            C[i][j] += A[i][k] * B[k][j]
```

<table>
<thead>
<tr>
<th>Implementation</th>
<th>Time (s)</th>
<th>Speedup</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Python</td>
<td>25,552.48</td>
<td>1</td>
</tr>
<tr>
<td>2 Java</td>
<td>2,372.68</td>
<td>11</td>
</tr>
<tr>
<td>3 C</td>
<td>542.67</td>
<td>47</td>
</tr>
<tr>
<td>4 Parallel loops</td>
<td>69.80</td>
<td>366</td>
</tr>
<tr>
<td>5 Parallel divide-and-conquer</td>
<td>3.80</td>
<td>6,724</td>
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<tr>
<td>6 + vectorization</td>
<td>1.10</td>
<td>23,230</td>
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<tr>
<td>7 + AVX intrinsics</td>
<td>0.41</td>
<td>62,323</td>
</tr>
<tr>
<td>8 Strassen</td>
<td>0.38</td>
<td>67,243</td>
</tr>
</tbody>
</table>

B. Kuszmaul, T. Schardl, S. Amarasinghe, C. Leiserson (MIT)
The next computing device?

?
Planar InGaAs MOSFETs

Lin, IEDM 2012, 2013, 2014
InGaAs FinFETs

Vardi, DRC 2014, IEDM 2015
InGaAs Vertical Nanowire MOSFETs

Xin Zhao

Zhao, IEDM 2013