Bitcoin and the Age of Bespoke Silicon

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This Talk

Introduction

An Overview of the Bitcoin Cryptocurrency

Bitcoin’s Computing Evolution

Bespoke Silicon

Interesting Facts about Bitcoin

- The most successful digital currency ever

  Since its deployment in Jan. 2009,

  - **11.7 Million** … Bitcoins (BTC) are in circulation
  - **$142** … is current value of 1 BTC (mtgox.com)
  - **$1.66 Billion** … is the total BTC Market capitalization

- Winklevoss Brothers →
  bought 1% of BTC supply and
  are creating a BTC ETF

- You can create (***mine)*** bitcoins with your computer!

What this talk focuses on:

- How Bitcoin mining has raced down the computing specialization hierarchy:
  - distributed CPUs
  - distributed GPUs
  - distributed custom FPGA boards
- And now…
  - Three groups of enthusiasts created three different ***bespoke*** ASICS that have displaced CPU/GPU/FPGAs
  - 80X cheaper/less energy than Intel, AMD, Xilinx…
  - No Venture Capitalists were involved
  - Silicon Valley was not involved
  - They were not backed by any big company
  - *How did they do this in an environment in which new chip startups are almost non-existent? (And can we replicate?)*

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Bitcoin: User View

- First step: create a bitcoin account
  - run code locally on your computer to create two numbers:
    - ***public key (also known as a BTC address)***: like an email address; people can send BTC to it
      - e.g., 1JVQw1siukrxGFTZykXFDtcf6SExJVuTVE
      - in many cases people publically advertise these
    - **private key**: lets you transfer BTC associated with your public key to somebody else's BTC address
      - 256-bit number
      - keep this in a safe place!
  - no interaction with outside world req'd to **create** account
- Next step: receive, spend and/or mine bitcoin in minimum increments of **1 *satoshi***

  = 1/100,000,000 BTC

Bitcoin Network

- The Bitcoin system:
  - maintains a global, distributed ledger of transactions (e.g. transferring bitcoin) called ***the block chain***, that***:***
    - tracks how many BTC are at each address
    - is replicated across many machines on the internet
    - is maintained via a consensus algorithm by those machines
    - contains a public record of every single transfer of BTC
  - the machines perform an computationally intense operation called ***mining*** that adds new blocks of transactions to the block chain
  - each block contains:
    - a cryptographic hash of the previous block in the chain, maintaining integrity and a total order of blocks in the chain;
    - a merkle hash of all transactions in the block

Bitcoin Network Consensus

- Other nodes will validate new blocks added to the block chain; e.g. no improper creation or destruction of bitcoin
- If the block is valid, nodes will use it as the base for new blocks being added; if they do not, they will use the previous block as the chaining point (a *fork*)
- This is the basis of the consensus algorithm that maintains the integrity of the block chain.
- A block is added roughly every 10 minutes (more on this later).
- Convention: your transaction is legit after 6 blocks have been added to the end of the block chain

Rewards for Bitcoin Mining

- You get 50 BTC *block reward* for adding a block to the chain; paid via a transaction included in the block.
- Reward drops by half every 210K blocks (four years). It has already dropped to 25 and will drop until it reaches a satoshi.
- Total BTC will never exceed 21M; 99% by 2032.
- User often specify a transaction fee (often .0005 BTC) for their transactions to incentivize nodes to add their transaction to the block.
- Miner collects these as well, but only amount to .25% of reward; but this becomes the main incentive when block reward is small.

Bitcoin Mining *Difficulty* (The Catch)

- To add a block, nodes find a ***nonce;*** a value in the block's header, that causes block's double-SHA256 hash to be less than a certain number, maxH.
- Basically, analogous to computing the inverse of a cryptographic hash → hard!
- Brute force (*increment nonce;* ***hash****; check; repeat*) is the only known method (otherwise SHA256 is easily invertible and a bad hash.)
- maxH is characterized by a number called the **network difficulty:** maxH = (0xFFFF << 208)/difficulty.
- Difficulty is scaled every 2016 blocks to keep network's block creation rate at 1 per 10 minutes.

Bitcoin Mining Profitability

- 6 blocks per hour * 24 hrs = 144 blocks/day
- 144 blocks * 25 BTC = 3600 BTC/day
- 3600 BTC/day = ~$518,000/day
- These mining rewards are spread across the world based on the % of **network hash rate;** basically the world's total brute-force hashing capability.
- Your reward is proportional to your % of the network hash rate.

– Good CPU:	5-15 MH/s;
– Good AMD GPU:	600 MH/s; $400 per GPU
– ASIC is:	300 MH/s; ~$4 per chip

A Brief History of Bitcoin

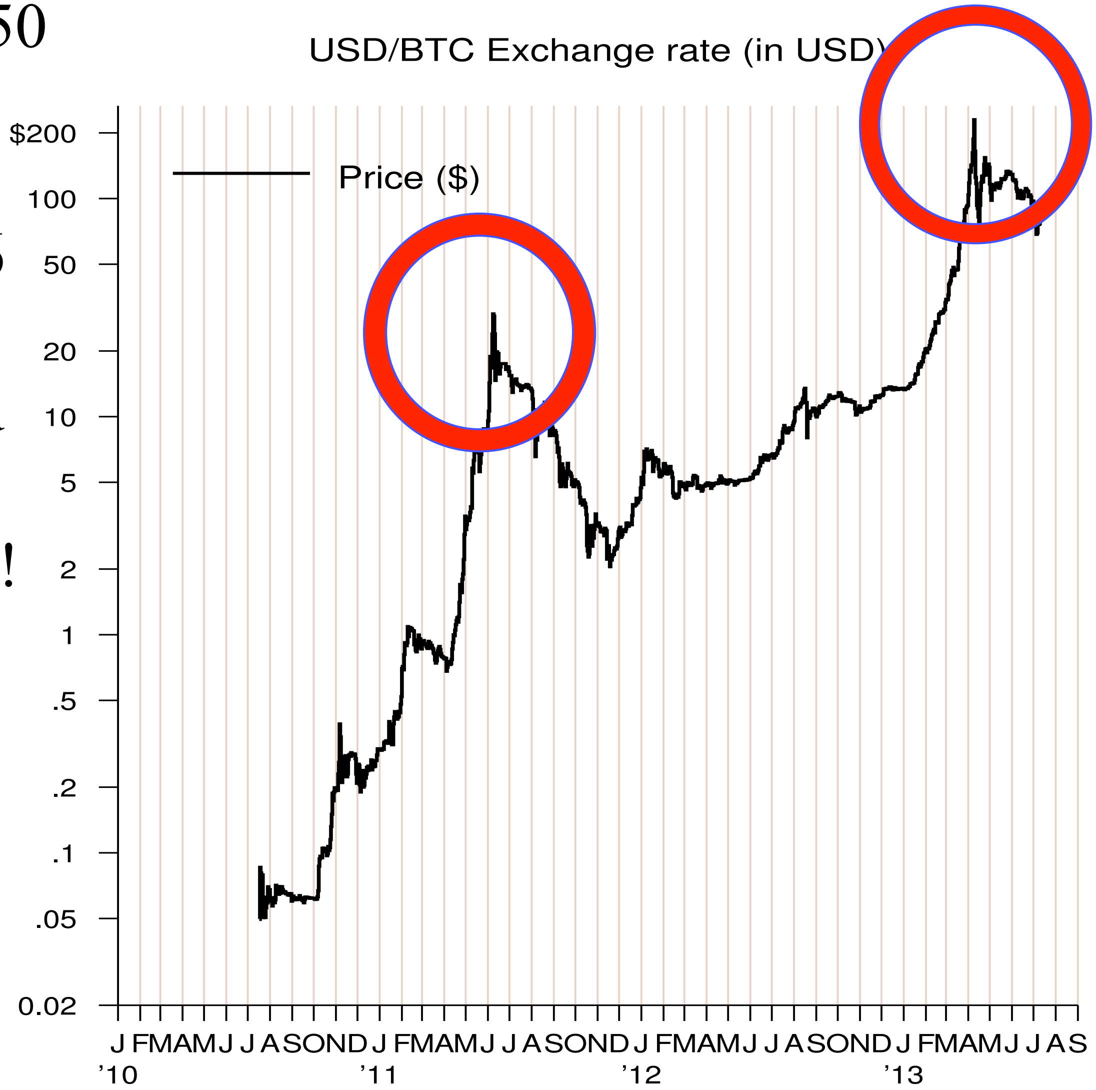
- Nov ‘08: *Satoshi Nakamoto posts Bitcoin paper*
- Jan ‘09: *System goes live*
- Jul ‘10: *USD/BTC Exchange Created*
- *Sep ‘10: GPUs start being used to mine*
- Apr ‘11: *Satoshi Disappears!*
- *Jun ‘11: FPGAs start being used to mine*
- *Feb ‘13: ASIC hardware appears*

The Value of a Bitcoin

BTC goes from $.05 to $150
in four years: 3000x

Two bubbles: $32 and $266

Early on somebody ordered
a pizza for
10,000 BTC = $1.5M!!



What do people see in Bitcoin?

- Not controlled by any central government
- Fixed money supply; inflation is bounded (21 M BTC)
  - beats gold as a value store
- Pseudo-Anonymous Transfers
  - like Paypal (gov't still can find out who you are)
- Irreversibility
  - no charge-backs like for VISA / Mastercard / Checks
- High portability and physical security
  - better than gold, cash, bank accounts, bearer bonds
  - memorize your private key
- Low transaction fees (5 cents to transfer $1B dollars)

How much will Bitcoin be Worth?

- 21 million BTC total currency supply
- 7.1 billion people
- → 338 *people per BTC*!
- Value of a BTC if it replaces world gold reserves
  - $71,000
- Value of a BTC if it replaces USD as world currency
  - $57,142
- Value of a BTC if BTC reaches VISA/MC mkt cap
  - $9,857

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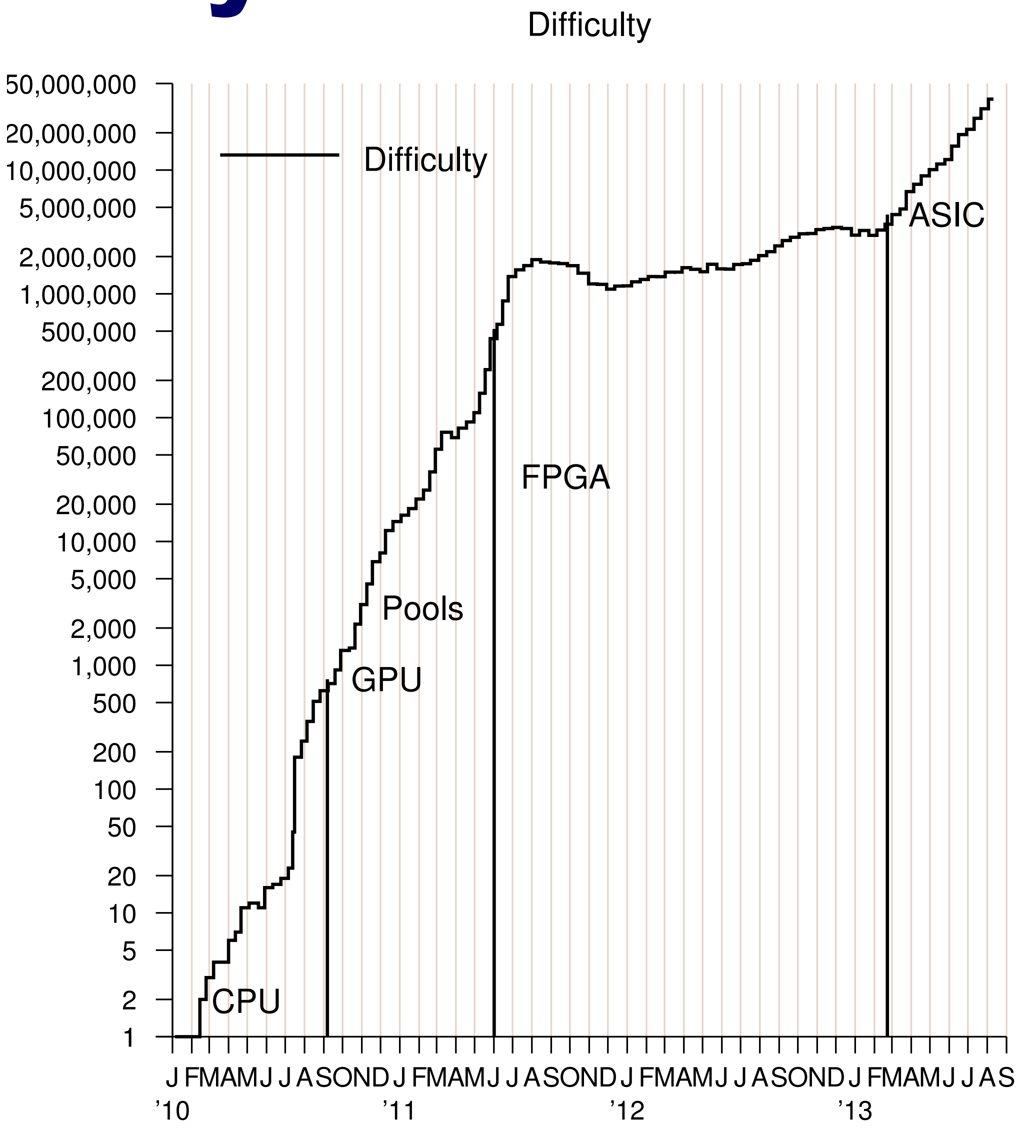
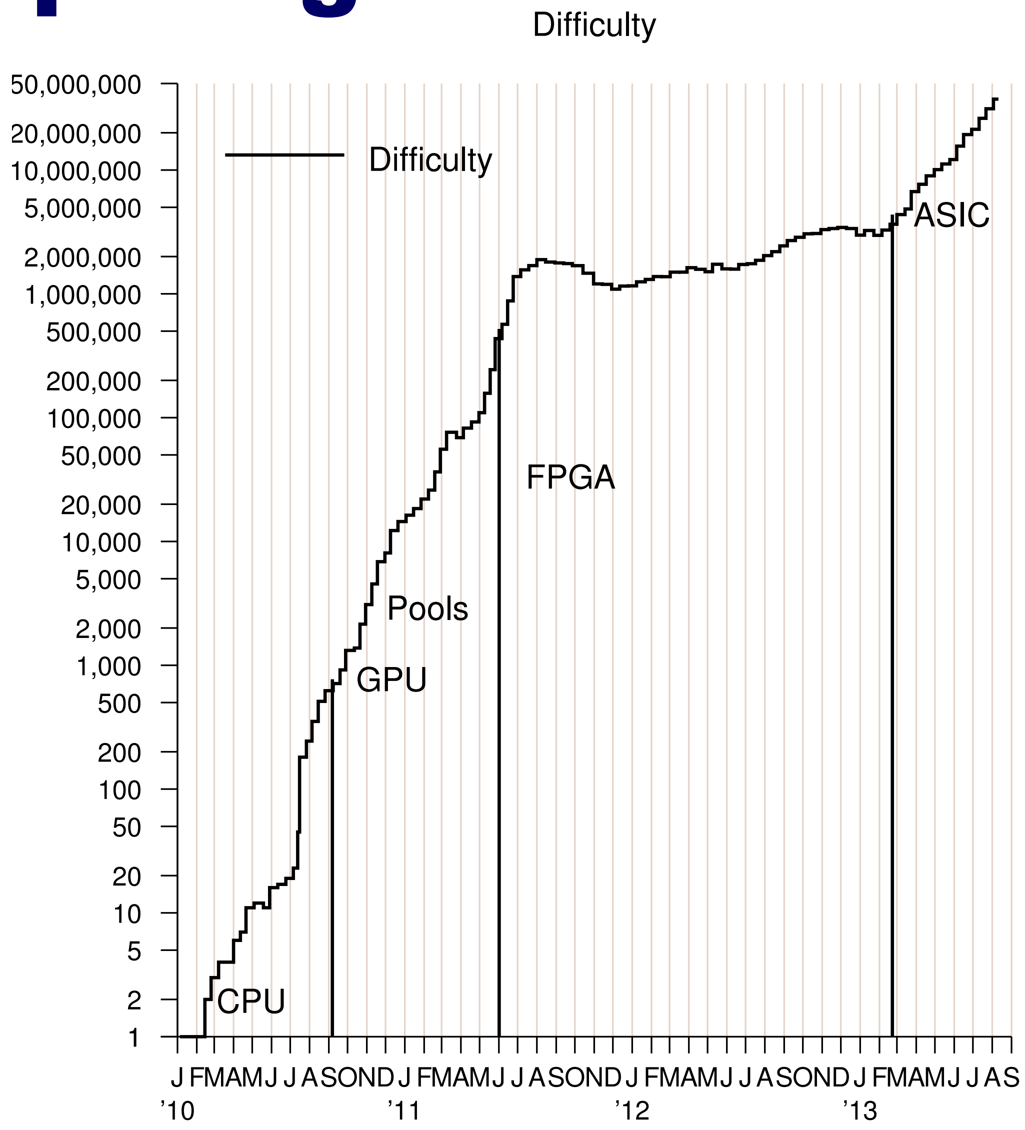
BTC Mining Difficulty

- Started at 1.
  - – a few CPUs
- Now at 104,000,000
  - – 300 million CPUs
  - – but actually: 400K ASICs
- Difficulty ramps as:
  - – new technologies arrive
  - – USD/BTC increases
    - more machines added
- Lines mark dates of introduction of new computing technologies



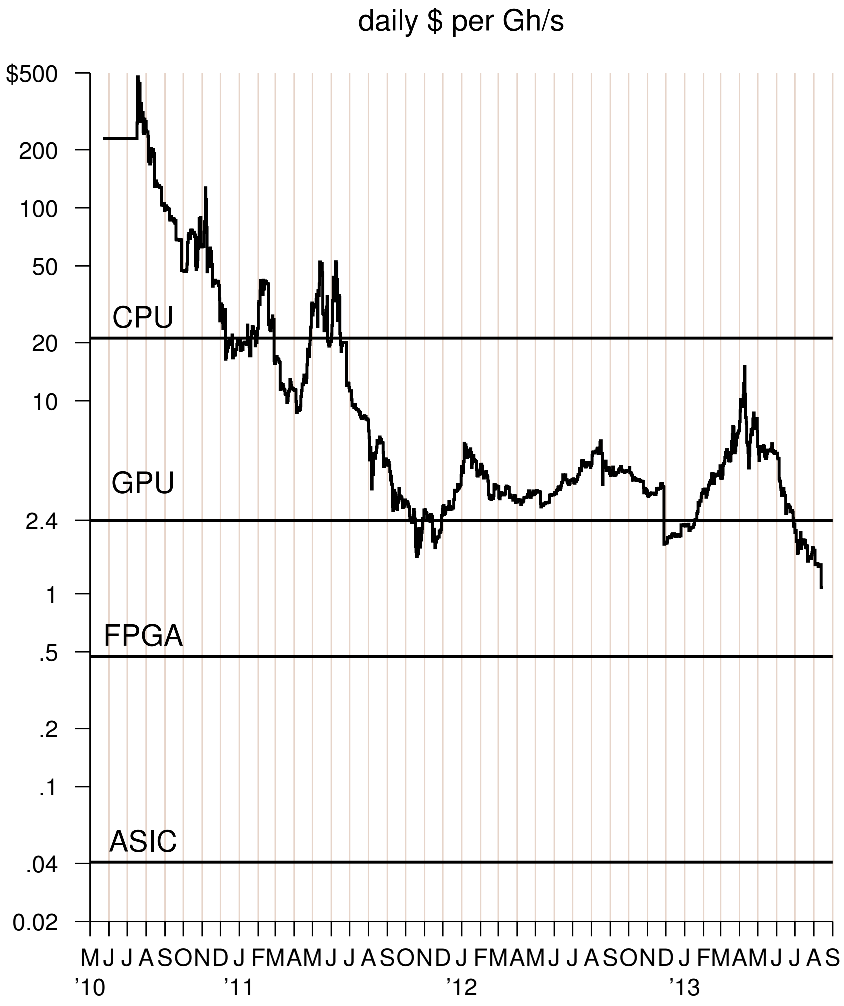
BTC Mining Computing Evolution



- CPU
- GPU
  - Portable OpenCL Imp
  - Completely unrolled double SHA256 hash
  - AMD >> Nvidia
    - instruction set match
    - microarch (VLIW) match
    - higher ALU density
    - memory BW not used
- FPGA
  - verilog
  - “gateway drug to ASIC”: boards, protocols, thermals, verilog
- ASIC

Energy Costs and USD/BTC Say when to unplug/plug HW

- daily $ per Gh/s falls as technology advances and more machines deployed
- daily $/GH/s rises if USD/BTC rises.
- Today, CPUs, GPUs, and even FPGAs do not recoup energy costs
- Rising USD/BTC: old machines get fired up.
- Steady state: cheap energy wins (Iceland?)



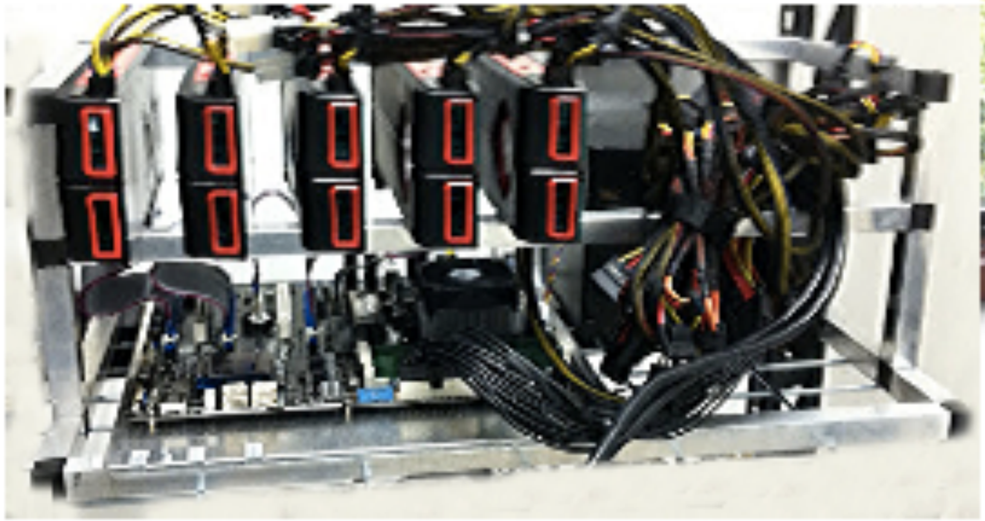
(USD .015 per KWh)

Gen 1: CPU

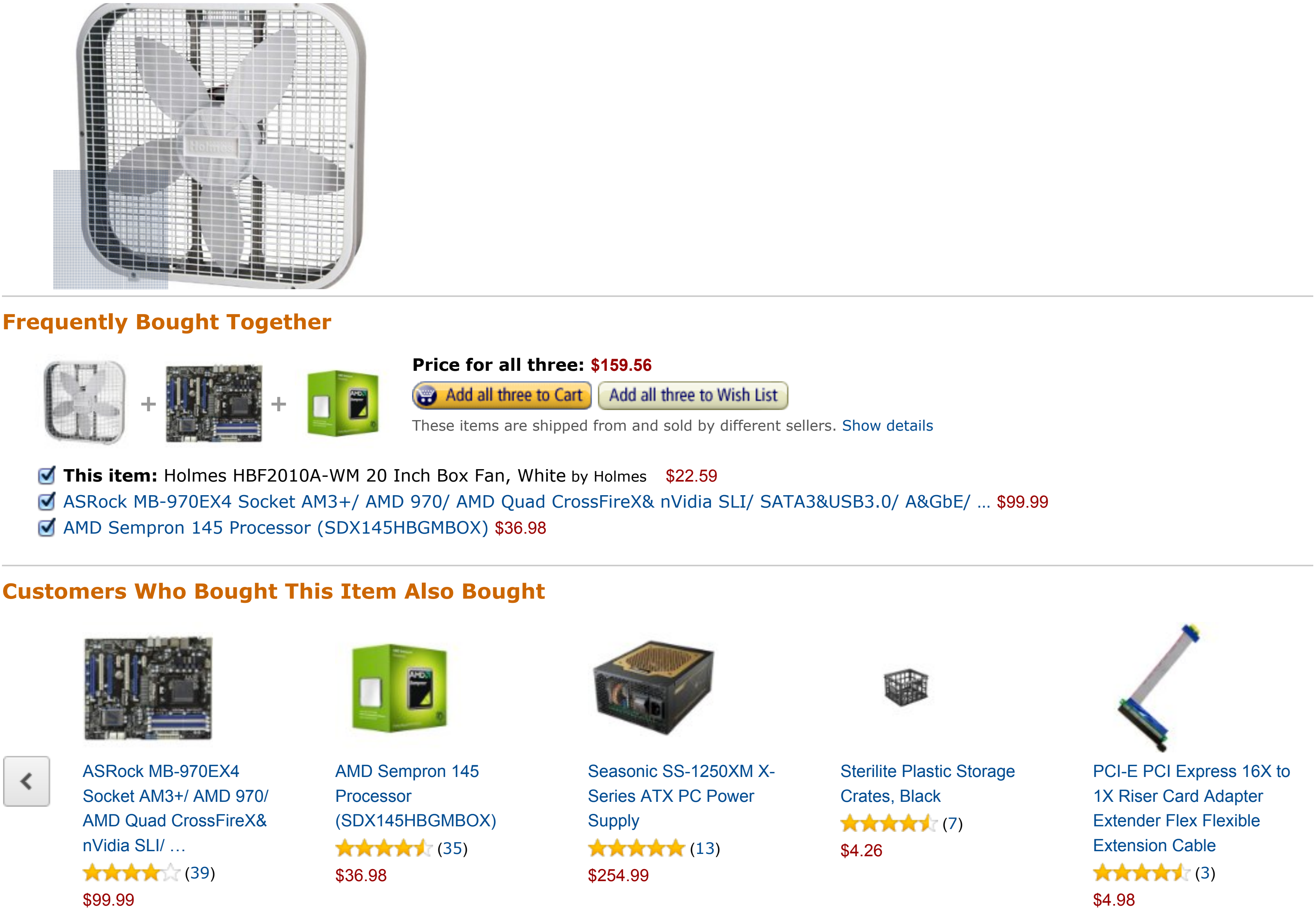
- CPUs
- Pooled Mining
  - Idea: mining a block takes longer and longer → hours, then day, then months, now years.
  - Solution: have groups of machines work together to reduce variance and uptime.
  - Solution: Divvy up the nonce space among many hosts, and have them get work from a central server, and they get paid for their share of nonce space explored.
  - Problem: Hosts skip work, reporting that they searched and found nothing, and collect BTC.
  - Solution: Hosts return results for blocks that are “close”; server duplicates a small subset of work among different clients.

Gen 2: GPU “Rigs”

- GPUs running OpenCL > 30x GH/s of CPU
- Key challenges in GPU systems
  - wasted $ and energy on CPU / PCB / DRAM
  - power delivery, heat dissipation problems
- Innovative solutions:



amazon Prime … “Gets” GPU Mining



Frequently Bought Together

Price for all three: $159.56

Add all three to Cart | Add all three to Wish List

These items are shipped from and sold by different sellers. Show details

- ☑ **This item:** Holmes HBF2010A-WM 20 Inch Box Fan, White by Holmes $22.59
- ☑ ASRock MB-970EX4 Socket AM3+/ AMD 970/ AMD Quad CrossFireX& nVidia SLI/ SATA3&USB3.0/ A&GbE/ … $99.99
- ☑ AMD Sempron 145 Processor (SDX145HBGMBOX) $36.98

Customers Who Bought This Item Also Bought

ASRock MB-970EX4 Socket AM3+/ AMD 970/ AMD Quad CrossFireX& nVidia SLI/ …
★★★★☆ (39)
$99.99

AMD Sempron 145 Processor (SDX145HBGMBOX)
★★★★☆ (35)
$36.98

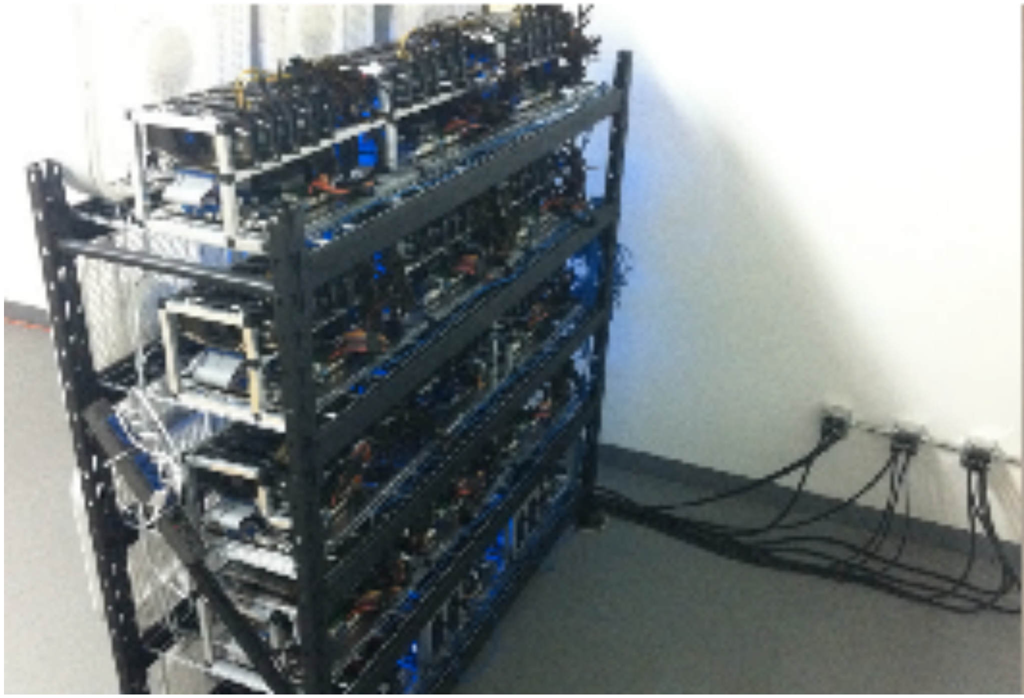
Seasonic SS-1250XM X-Series ATX PC Power Supply
★★★★★ (13)
$254.99

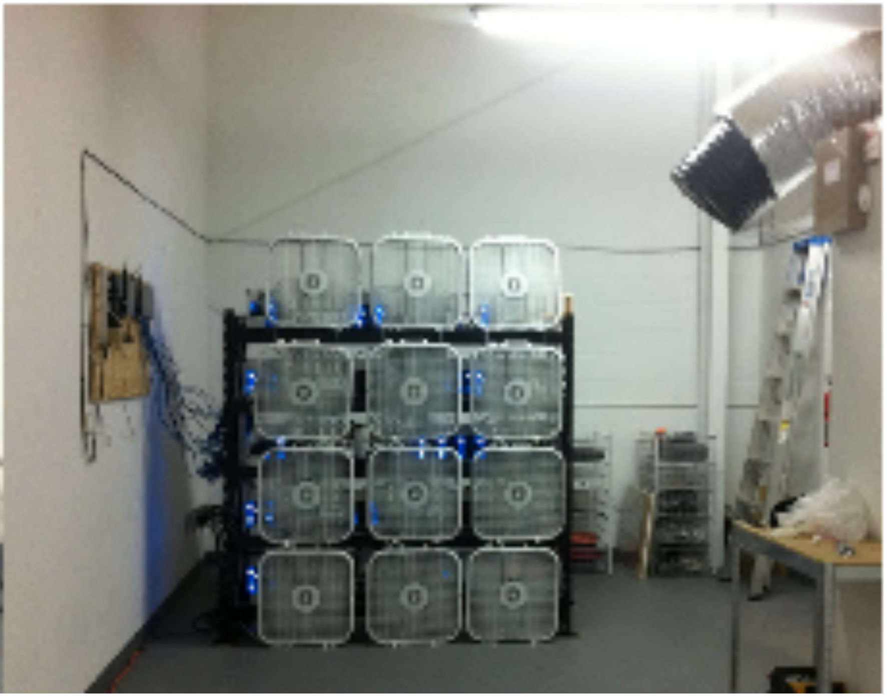
Sterilite Plastic Storage Crates, Black
★★★★☆ (7)
$4.26

PCI-E PCI Express 16X to 1X Riser Card Adapter Extender Flex Flexible Extension Cable
★★★★☆ (3)
$4.98

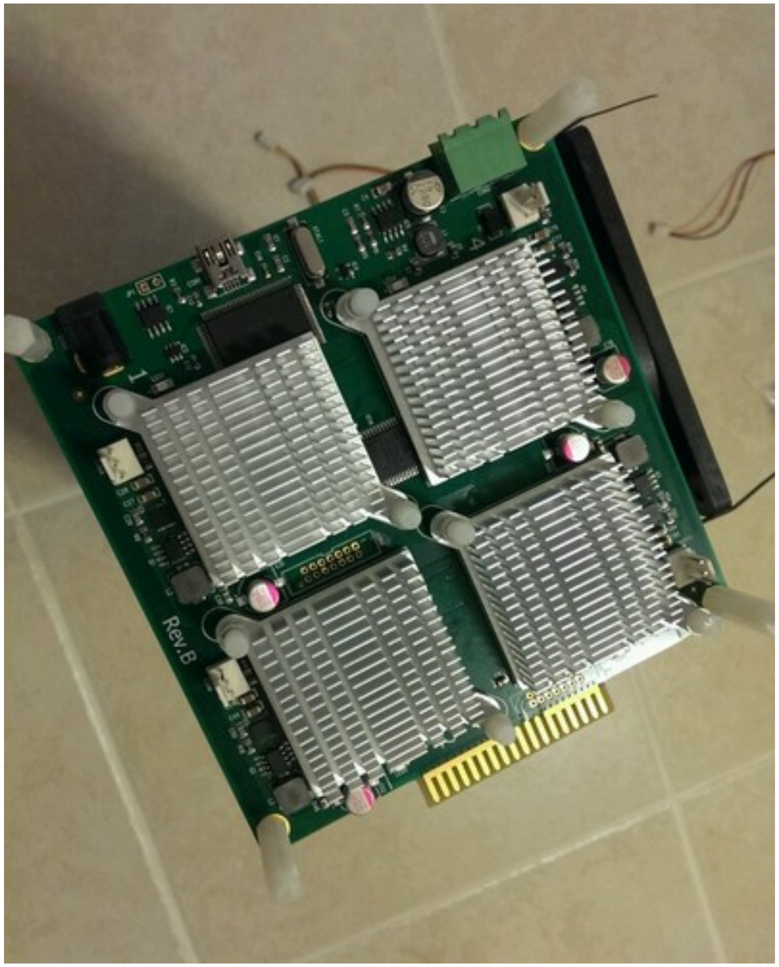
Gen 2.5:
“GPU Datacenter in my Garage”

- Renting data centers was often too expensive
- Roll your own
  - – 69 GPUs in one rack
  - – Box fans and heat ducts





Gen 3: FPGAs



- 1-2 pipelines per FPGA
- 128-stage pipeline == 1 double SHA hash/cycle
- ~ 216 MHz
- academic FPGA boards: insufficient power; custom boards req'd
- utilized best "consumer" FPGAs (Spartan-150)
- ~5-8x energy efficiency v. GPU, same cost: but *no resale market! Wins only on* ***Long-term*** *TCO.*
- ASICs came out too quickly after FPGA for FPGAs to obsolete GPUs.

Gen 4: ASICs

- Built and financed by enthusiasts ***on online forums*** – not by existing semiconductor companies or venture capitalists.
- Three parallel efforts:
  - Butterfly Labs (BFL)
  - ASICMINER
  - Avalon
- With the deployment of SoCs and advanced process nodes, new digital chip startups are becoming increasingly rare…
- These efforts are counter to that trend; I refer to them as *interesting cases of* ***bespoke silicon*** – custom built silicon tailored to a particular purpose.

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Bespoke Silicon: BFL

- Pre-June 2012: Bitcoin forums had constant musings about the potential promise and catastrophe of ASICs, even as GPUs and FPGAs became coming.
- June 2012: Butterfly Labs (BFL), an FPGA miner vendor, announces it is taking pre-orders for:
  - $149 “Jalapeno” at 4.5 GH/s (30x cost/perf over GPU),
  - $1,299 “Single” at 60 GH/s and
  - $30,000 “Minirig” at 1,500 GH/s
  - note: ***entire network was only 12,000 GH/s at the time!***
  - units were sold <u>on a pre-order basis</u>, with delivery promised in November. The funds went towards financing the effort (a la the Kickstarter model.)

Bespoke Silicon: BFL

Bespoke Silicon: BFL

- 65-nm GlobalFoundries process, 7.5 mm x 7.5 mm
- High NRE: $500K - $1M estimated
- 16 lanes of double-SHA256 pipelines @ ~300 MHz
  - like 16 FPGA pipelines in one chip; lanes offer yield control
  - Originally: QFN package; later: 10x10 BGA 144
- Original power estimate: .8W per GH/s
- Actual: 6W per GH/s → Need higher end package
- First HW slips from Nov ‘12 to April ’13
- BFL gave **daily updates** on their progress
  - Tens? of Thousands of investors/customers!
  - Delays have greatly reduced payout to now-angry customers
  - # of units ordered may have made this inevitable!

Bespoke Silicon: ASICMINER

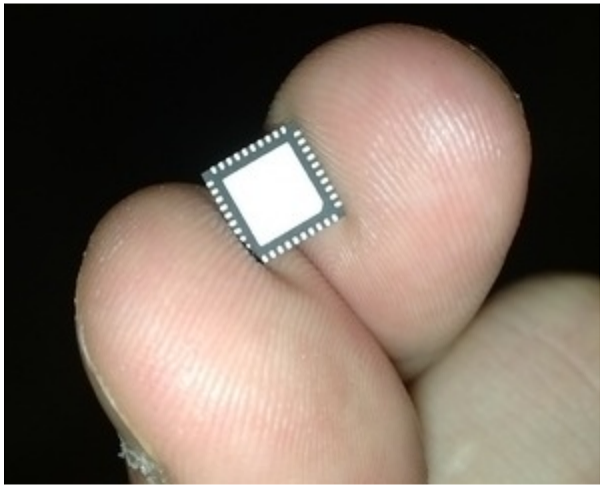
- Early July, after BFL took pre-orders
- Chinese group; connections to Shenzhen
- Raised funding through 100’s posts to online forum bitcointalk.org; answering questions about every detail of their operation: business plan, CAD flow, design, qualifications, foundry costs, deployment strategy. Very impressive.
- Did an IPO on a non-SEC regulated online stock exchange **denominated in bitcoin** (!)
- 1/400K share of weekly profits for .1 BTC
- Business plan: build machines and mine 12 TH themselves; then sell hardware.
- *Returned over 40x to investor – in BTC* (~400x in $)

Bespoke Silicon: ASICMINER

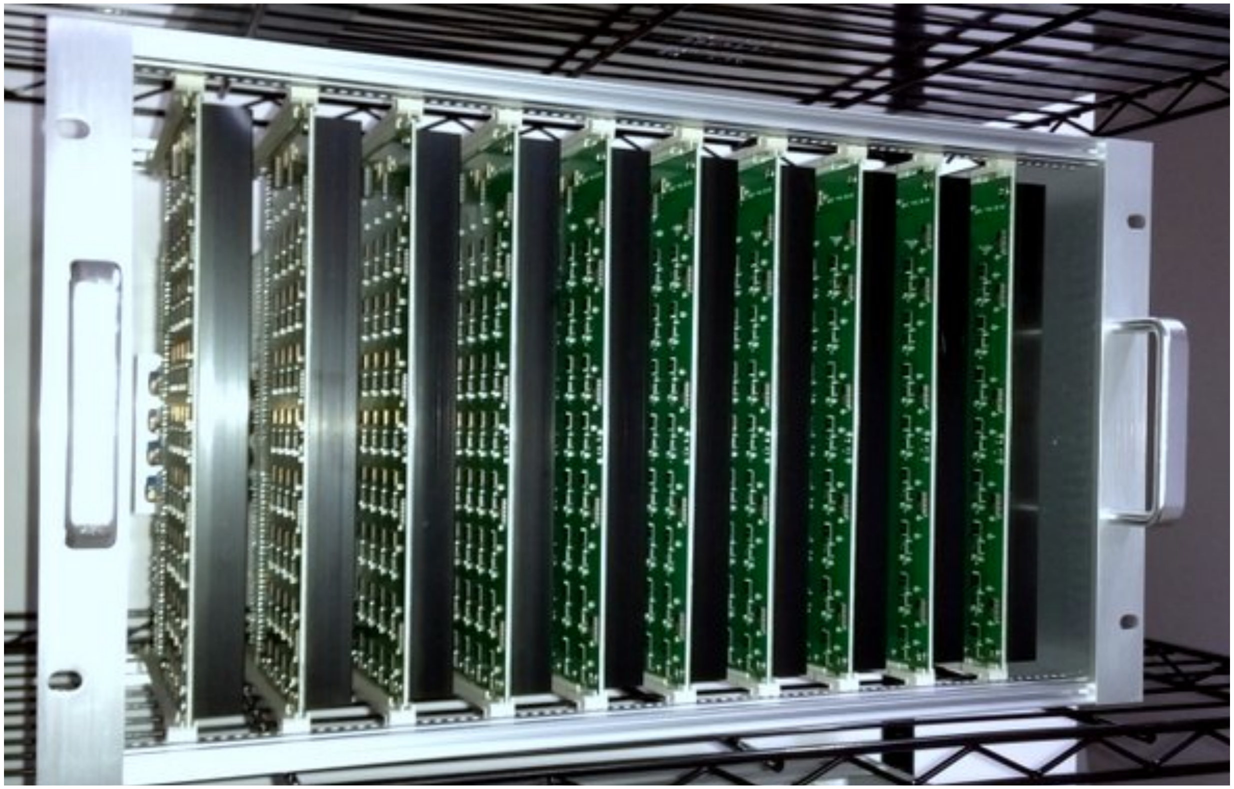
- 130-nm 6M China-based process, 6 mm x 6 mm
- MLM process: trade mask costs for stepper costs
- Low NRE (~150K) (one third of BFL's)
- 1 lane of double-SHA256 pipelines @ ~335 MHz
  - just like FPGA version; 1 hash per clock
- 40-pin QFN package; 4.2 W per GH/s est.
- Detailed posts to investors every week
- Unprecedented view into the day-to-day working of a shuttle run --- layer by layer report of shuttle progress!
- First Bitcoin ASIC: Dec 28, 2012
- 2 TH/s deployed: Feb 14, 2012
  - complex ordeal to create a reliable datacenter in Shenzhen

Bespoke Silicon: ASICMINER

- Clever packaging: QFN package has large center ground pad that can transfer heat directly to PCB
- No heatsink or local fan costs
- Heat is spread evenly across large surface



credit: mineforeman.com



Bespoke Silicon: ASICMINER

- Later, they sold:
  - USB keys containing a single chip; using auctions
  - PCB boards; using auctions
- No reliance on pre-orders; fast Shenzhen supply chain
- Happy customers

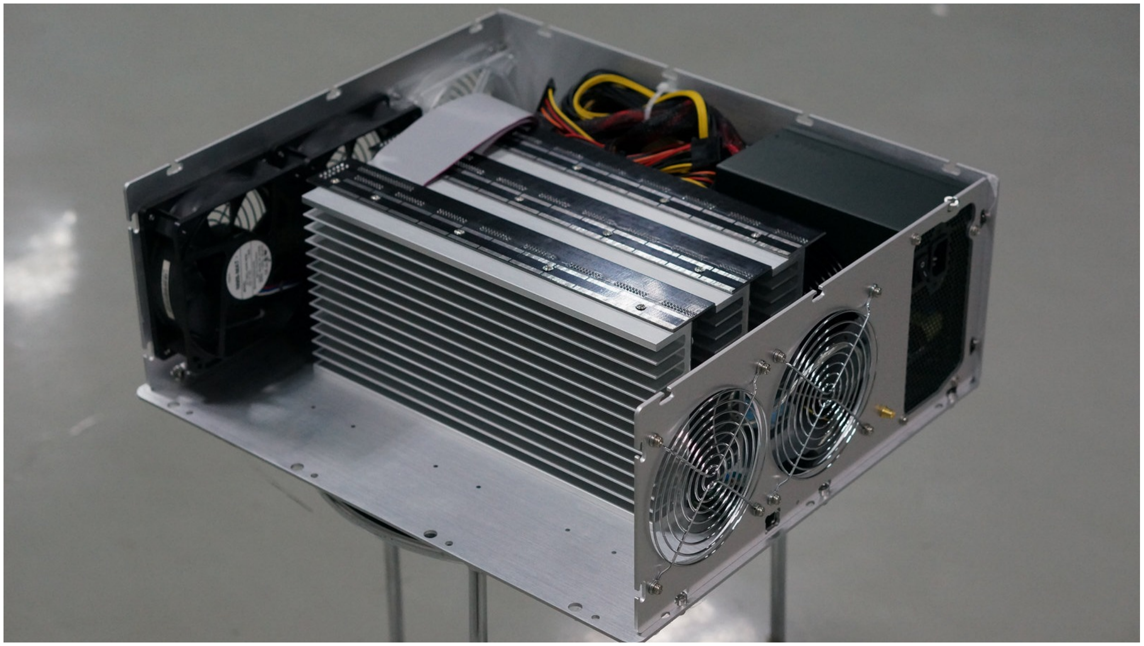
Bespoke Silicon: Avalon

- Another Chinese group; connections to Shenzhen
- Jul Preorders: 300 60 GH/s Rigs @ 108 BTC = $1299
- Clever: BTC denomination drives demand for BTC!
- **Delivered first ever ASIC rig to customer Jan 30**. Earned almost 15 BTC in first day!
- After 1st batch, 2nd and 3rd batch of 600 machines each, at 75 BTC, about $7500 at the time
- Then, sold lots of 10K chips for 780 BTC, or $78,000!
- Users banded together to do “group buys” on forum, and to design and procure PCB boards. *(Imagine trusting somebody with $78,000!)*
- Delays in Shenzhen supply chain / shipping → Unhappy customers; but they refunded (unlike BTC)

.

Bespoke Silicon: Avalon

- 110-nm TSMC, 4mm x 4mm, ~220 MHz
- Founder included FPGA miner designer
- Single double-SHA256 pipeline
- **300 chips** across 3 blades in 4U chassis
- Smuggle systems out of China and ship through HK
- Standard PSU
- QFN package with metal platesink.



source: gizmodo

Bitcoin Scaling into the Future

- Bitcoin is worst case for dark silicon
  - only linear improvement in throughput and energy per hash due to scaling from 65-nm to 10-nm (6.5x)
- Dark Silicon and Low-Power techniques all apply
  - for instance, near threshold (NTV):
    - no RAMs, little synchronization
  - designs are based on FPGA designs where pipeline registers were free.
  - Next generation will reduce pipelining to bring clock energy under control.
- Probably about 100x left → ~6 W per TH
- Maybe opportunities for specialized circuit design a la DRAMs due to Bitcoin’s replicated nature

Observations for Bespoke Silicon

- Specialized devices ***can*** beat general-purpose devices in cost/performance by orders of magnitude
  - if the application benefits from “weak scaling”
- Users are willing to finance when VC’s were not.
  - But they were demanding; even annoying
  - Bitcoin had a (local) linear utility curve for performance
- CPU->GPU->FPGA->ASIC: good progression for new domains: scale up effort as premise is proved
- Old process generations combine well w/ bespoke
  - specialization compensates for “old silicon”
  - low startup costs for trying new ideas
  - time-to-market was inversely correlated with feature width!
  - avoid design complexity issues associated w/ power density
    - e.g. BGA versus QFN; active vs. passive cooling; leakage; power grid

Observations for Bespoke Silicon

- Have we lost the ability to do cheap chips in the US?
  - Two of the three teams were from China.
  - They were the best at executing.
- Academia’s fixation on latest process generations does not prepare HW students to do quick startups, unlike their software peers.
  - Are we hamstringing our students and killing innovation?
- Training on million-dollar tools makes it hard to “design cheap” when students exit academia and have to pay
- Technologies like multi-layer masks can bring down the cost of chip startups
- ***Bitcoin is a unique case; but could offer insights into how to build new, bespoke HW for new domains for cheap and revitalize the chip industry!***