

Designing a Commercial Libre RISC-V SoC

Ethical Strategic Leveraging of the benefits
of Libre and Open SW/HW
for pure unadulterated Commercial gain

Chennai 9th RISC-V Workshop

July 15, 2018

Credits and Acknowledgements

- ▶ The Designers of RISC-V
- ▶ The RISC-V Foundation
- ▶ The Shakti Group, and IIT Madras RISE Group
- ▶ Prof. G S Madhusudan
- ▶ Neel Gala
- ▶ Rishabh Jain
- ▶ Members of the RISC-V Open Groups (SW/HW/ISA)
- ▶ Libre and Open Software and Hardware Communities
- ▶ Richard Herveille (RoaLogic), Edmund Humenberger, Clifford Wolf (Symbiotica EDA), Rudi (Asics.ws), Enjoy-Digital.fr, Alex Forenchich, LowRISC Team
- ▶ Anonymous Sponsor

Why, How, What?

- ▶ Why? Because these days it's just not necessary to make [un]ethical compromises in order to make a profitable, desirable mass-volume product
(There's enough companies doing that: where it's got us??)
- ▶ How? By leveraging the long-established strategic cost and maintenance benefits of libre-licensed software (and HDL) and *making sure that the people who provide it are financially rewarded*. Also by empowering diverse team collaboration
- ▶ What? A 2.5ghz RISC-V 64-bit SoC that has a 3D Embedded GPU, 1080p Video decode, and interfaces to make it attractive for use in tablets, netbooks, industrial embedded and more. 22nm or less, under 400 pins, under USD \$4.
All sounds obvious... but is it practical and achievable?

Definitions

- ▶ **Business:** the provision of a service and being commensurately financially rewarded for doing so
- ▶ **Spongeing:** the provision of a service and being taken advantage of for doing so (*cf: Professor Yunus*)
- ▶ **An ethical act:** an act that increases truth, love, awareness or creativity for one or more people (including yourself), *without* reducing those same four qualities *for anyone*
- ▶ **The Four Freedoms:** the rights and guarantees associated with and embedded within GNU Licenses (*cf: FSF*)

Is it possible to ethically do business and respect the Four Freedoms? That's where it gets interesting, as there are even cases where the Four Freedoms are unethical. Note: google's former motto "don't be evil" is clearly (unintentionally) unethical

Does what we want already exist? Surely this is nonsense!

Processor	Ingenic j4775	Rockchip RK3188	Alwinner A64	Qualcomm Snapdragon 410c	Alwinner A20	Freescale iMX6	Any Intel Atom SoC
Power consumption	2 watts	Est 4-5 watts	Est 5 watts (clock-limited)	Est. 4 watts	Max of 3.5 watts	6 watts	TOO MUCH
NDA	NO	YES	YES	YES	YES (most info is public)	No	YES
Datasheets	YES	Sort-of	Yes	Mostly	YES	Yes	Yes
PMC Available	YES	Yes	Yes	Yes	YES	Yes	Yes
Reference Schematics	YES	Yes (thank you Tom Cutler)	Yes	Yes	YES	Yes	NO
Reference PCB	YES	Yes (thank you Tom Cutler)	Yes	NO (PCF's only)	YES	Yes	NO
Tech support	Community-based	Community-based	Community-based	NO	Community-based	Yes	NO
GPL-compliant bootloader	YES	MAYBE (have to check)	NO (Hobbit)	YES	YES	Yes	Under NDA only
GPL-compliant u-boot	YES	Yes	YES (sort-of)	YES	YES	Yes	NO (contains spying hardware)
GPL-compliant kernel	YES	Yes	YES	YES	YES	Yes	Yes (but with spying software)
GPL-compliant 3D GPU	YES	NO (MAL)	NO (MAL)	YES (Freedom)	NO (MAL)	Yes (Etchak)	YES
GPL-compliant Video Engine	YES	NO	NO (reverse-engineered partly)	NO	NO (part reverse-engineered)	NO (proprietary)	YES
Example OS (full source)	Yes (but more "Libre" (too old))	Yes	Yes	YES	YES (huge!)	Yes	YES
Estimated time	2-3 months	2-3 months	2-3 months	4-6 months	2-3 months	2-3 months	8-10 months
Estimated cost	\$10,000+	\$10,000+	\$10,000+	\$25,000+	\$10,000 appx	\$10,000 appx	\$100,000+

Analysis of SoCs over the past 7+ years (answer: no)

Breakdown of non-existence of fully-Libre SoCs

- ▶ **iMX6**: Libre bootable, Vivante 3D GPU (libre etnaviv) but proprietary VPU (and a power-hungry Cortex A9)
- ▶ **Allwinner SoCs**: mostly Libre bootable, VPU reverse engineered; GPU: MALI or PowerVR (i.e. proprietary)
- ▶ **Rockchip SoCs**: good but using MALI or PowerVR.
- ▶ **TI OMAP**: good but using PowerVR. and expensive.
- ▶ **Samsung**: good but using MALI.
- ▶ **Ingenic jz4775**: GREAT! performance sucks (1ghz MIPS32).
- ▶ **Broadcom SoCs**: Cartelled. and boots from the GPU

Basically there does not exist one single commercial SoC that provides full source code for all functions (CPU, GPU, VPU) with modern performance. Which is kinda bizarre if you think about it

What would a good (Libre) boring, mundane SoC have?

- ▶ Cover a lot of different scenarios (embedded, tablets, industrial, netbooks, crypto-currency mining).
- ▶ Decent performance with high efficiency. RISC-V: 40% more efficient than ARM / Intel. Shakti a good candidate: 2.5ghz and 120mW per core @ 22nm.
- ▶ 1080p video: y'all gotta watch cute kittens on youtube, right?
- ▶ 3D GPU: y'all gotta play Angri Burds, right? (or Minecraft)
- ▶ No spying back-door co-processors (to steal crypto-wallets)
- ▶ No Spectres, no Meltdowns.

Basically quite boring and mundane. No Monster Performance, no AI stuff, no special sauce. Just a plain-old SoC, 40% more power efficient than ARM/Intel, and not spying on end-users, that's all

How on earth does an ethical Libre SoC make money???

- ▶ Simple answer: Mask Rights.
- ▶ Without Mask Rights: by having a desirable product, and packaging it for a customer (i.e. by being a middle-man a service is still being provided for which payment etc. etc.)
- ▶ Without a desirable product or customer(s): err... you don't. (cf: definition of Business)
- ▶ By not having high NREs (leveraging back-to-back deals, and helping others fulfil their needs and goals)

Detachment from the goal also helps. If someone else makes this product then GREAT! I can go do something else

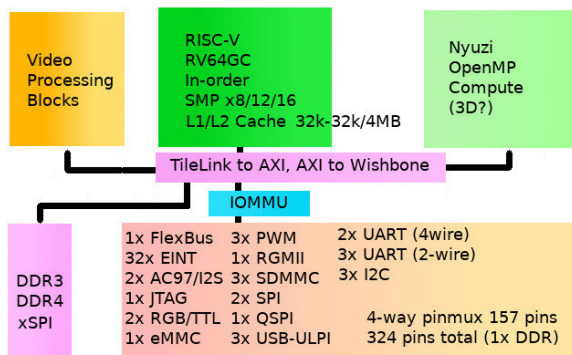
Main point: please do not automatically assume Ethical and Libre is non-commercial. It's not nice, and it's not helping

Things wot are "off-limits"

- ▶ Customer entrapment (through proprietary software).
Strong business case for not entrapping customers:
<https://tinyurl.com/most-productive-meeting-ever>
- ▶ Funding, endorsing, supporting or empowering unethical Companies, Organisations, Cartels and Individuals.
(cf: definition of an ethical act).
- ▶ Being totally inflexible / unrealistic. Goals have to be met: it's no good being an idiot about that. e.g. if a Libre 3D GPU really can't be made, use Vivante GC800 (with etnaviv).
- ▶ Spying back-door co-processors a no-no. Sovereignty is critical. Russia has Baikal. China has Loongson.

Still no real show-stoppers to making money (or product): it's just slightly harder, that's all. Ultimately it's about confidence.

Interfaces, Block Diagram, of the Libre-RISC-V SoC



Separate Power Domains for GPIO banks, Variable voltages required, low-power sleep states etc. Quite involved

Hardware / Development Complexity Comparison

- ▶ **Server:** relatively easy. PCIe, RapidIO, XAUI, SATA, GbE, 10GE, DDR3/4 (or HMC) etc. etc. No multiplexing: all interfaces dedicated and high-speed differential pairs.
- ▶ **Desktop:** really just a variant of Server. Graphics is a PCIe Card (except if integrated). Peripherals often done in dedicated external ICs ("Southbridge" concept)
- ▶ **Embedded:** also pretty easy. Really needs a pinmux. Low clock rate, low power mode. e.g. SiFive Freedom U310.
- ▶ **Mobile:** HARD. Performance/Watt matters => variable core voltage domains *per core*. Number of pins matters (affects yield and package cost). Cost matters. Pinmux critical.

Bottom line: Mobile-class processors are challenging!

Proprietary vs Libre-licensed Interface HDL

- ▶ DDR3/4: challenging! \$1m for single-use, single instance.
Symbiotic EDA: \$600k for PHY; CERN developed a Controller
http://libre-riscv.org/shakti/m_class/DDR/
- ▶ HyperRAM (JEDEC xSPI): lower risk than DDR3/4
http://libre-riscv.org/shakti/m_class/HyperRAM/
- ▶ RGMII: several available (saves \$50k)
http://libre-riscv.org/shakti/m_class/RGMII/
- ▶ UART, SPI, I2C, PWM, SD/MMC: all libre (except eMMC).
- ▶ Shakti Group has FlexBus, QuadSPI, SRAM, many more.
- ▶ RGB/TTL: R. Herveille (SSD2828, SN75LVDS83b, TFP410a)

Basically there's no compelling reason to spend vast sums on proprietary HDL. Sorry Cadence / Mentor / Synopsis / whoever

Challenging Stuff [1] - Memory Interfaces

- ▶ DDR3/4 PHYs are analog and very high speed. Impedance training. Extreme timing tolerances on parallel buses. No surprise proprietary cost is USD \$1m and above.
- ▶ Symbiotic EDA will do (Libre) PHY layout for USD \$300k, time to completion for chosen geometry: 8-12 months.

Silicon-proven but still risky. What are the alternatives?

- ▶ FlexBus/SDRAM (low clock, lots of pins, single-data-rate).
- ▶ HyperRAM (aka JEDEC xSPI) 8-bit SPI 166mhz or DDR-300. 300mbyte/sec for only 13 wires, not bad! (We'll take several) http://libre-riscv.org/shakti/m_class/HyperRAM/
- ▶ HMC: insanely fast, very low power. OpenHMC (LGPL) <https://opencores.org/project/openhmc>

Challenging Stuff [2] - Video Decode Engine

- ▶ Richard Herveille's Video Core Blocks
https://opencores.org/project/video_systems
- ▶ Symbiotic EDA MP4 decoder in FPGA
- ▶ H.264 seems to have been done...
https://github.com/adsc-hls/synthesizable_h264
- ▶ Really needs SIMD (or better, not-SIMD)
http://libre-riscv.org/simple_v_extension/
- ▶ Definitely needs xBitManip (parallelised by Simple-V)
<https://github.com/cliffordwolf/xbitmanip>

SIMD is insane. $O(N^6)$ opcode proliferation. See <https://www.sigarch.org/simd-instructions-considered-harmful/> (1): P-Ext designed for Audio. (2): Investigate RI5CY's SIMD

Challenging Stuff [3] - Power Management

- ▶ Been done before (many times), but not as a Libre Design.
- ▶ Sanjay Charagulla: GlobalFoundries 22nm mobile process can reach as low as 0.4v
- ▶ GPIO Banks need per-bank VREF (1.8v? to 3.3v)
IO pads need built-in level-shifting to convert to CPU VCORE
- ▶ Each core needs independent variable-voltage capability and independent shut-down (PMIC supplies external voltage)
- ▶ DDR RAM still needs refreshing (even in sleep mode)
- ▶ Extra RV32 (PicoRV32?) always-on core for wake-up / RTC
- ▶ PLLs are Analog. fun fun fun in the sun sun sun...

Really need help. PLLs, Analog stuff: specific domain expertise.

Fall-back example: <https://www.dolphin-integration.com?>

Challenging Stuff [4] - Libre 3D GPU. Sigh.

- ▶ Actual requirements quite modest: 30MP/s 100MT/s 5GFLOPS but power/area is crucial (2mm^2 @ 40nm, 1W)
- ▶ Nyuzi, MIAOW, GPLGPU (Number Nine), OGP.
- ▶ Nyuzi based on Larrabee. Jeff Bush really helpful.
- ▶ MIAOW is an OpenCL engine. GPLGPU is fixed-function
- ▶ Nyuzi lessons: Software-only rendering not enough. Getting through L1 cache takes most power. Fixed functions such as parallel FP-Quad to ARGB Pixel, and Z-Buffer needed.
- ▶ Fallback is GC800 (\$250k) *contact me if you can do better!*

Jacob Bachmeyer's Cache-control proposal turns L1 Cache into scratchpad RAM. RVV is just too heavy (sorry!), Simple-V much more light-weight and flexible (O(1) ISA proliferation)

Challenging Stuff [5] - Public Custom Extensions

- ▶ GPUs are usually done with incompatible ISAs and effectively doing OpenGL over IPC / RPC (Remote Procedure Calls)
- ▶ Much simpler: GPGPU "one ISA" approach. Custom-extend the core ISA to handle 3D, use Gallium3D-LLVM.
- ▶ Now add Video Extensions. and SIMD etc and **we are well beyond the only 2 available 32-bit custom opcodes**
- ▶ Due to the Libre nature of this project, the custom opcode space will be "dominated" by high-profile public hard-forks of gcc, binutils, llvm etc. Which isn't going to go down well.
- ▶ ISA "Conflict Resolution" is therefore absolutely critical
http://libre-riscv.org/isa_conflict_resolution/

Remember AltiVec. Learn from Intel. This is everyone's problem.

Interesting Missing Stuff [1] - Pinmux

- ▶ Pinmux: multiplexer of functions onto pins
DRAM Cell != DDR3/4, Mux Cell != Muxer
- ▶ Strategically extremely important to Commercial SoC success
STMicro, Rockchip, Freescale, Samsung, TI, **EVERYONE**
- ▶ Bizarrely, a libre-licensed multi-way Pinmux doesn't exist.
not on anyone's radar. at all. SiFive IOF not enough.
- ▶ Verification (scenario analysis) and auto-generation of TRM, header files, device-tree files, pretty much everything makes sense (to any "lazy" Software Engineer...)
- ▶ Corporations with legacy pinmux unlikely to be interested.
- ▶ <http://git.libre-riscv.org/?p=pinmux.git>
http://hands.com/~lkcl/pinmux_chennai_2018.pdf

Interesting Missing Stuff [2] - AC97/I2S, USB2 PHY

- ▶ Rudi (Asics.ws) donating time to create a Multi-Protocol Audio Controller: AC97, PCM, PDM, I2S
http://libre-riscv.org/shakti/m_class/AC97/
- ▶ USB2 is... convoluted. UTMI-ULPI-USB2 PHY
USB2-PHY not confirmed (Rudi has one)
Also Rudi has DDR (8-pin) variant of ULPI
http://libre-riscv.org/shakti/m_class/ULPI/
- ▶ USB3 not necessarily a good idea to put into Libre-RISCV
Daisho USB3 Pipe exists, TUSB1310a PHY is 175 pin FBGA!
- ▶ Libre SD/MMC typically at "Open" Level 20MB/sec appx.
Full spec and eMMC needed (Rudi again).

Trying to keep interfaces all-digital (USB3 isn't, HP/Mic definitely isn't). Use external (Analog) PHYs and/or Multi-chip Module

Which Processor Cores to use?

- ▶ Shakti RV64 at the top of the list, not just for technical reasons, but for the Shakti Group's goals and vision.
- ▶ Libre 3D GPGPU (SMP RV64 plus accelerated custom ISA) would make things interesting (3D app pinned to a non-uniform but SMP architecture)
- ▶ Video Processing again is reasonable to be a different RV32/64 Core (SMP or otherwise), possibly not even RV at all (MIPS, OR1200)
- ▶ RV32 (PicoRV32?) always-on definitely needed (sleep mode)

Ultimately, decisions are flexible, heavily weighted towards "what does good and doesn't do bad" as well as cost vs risk

Summary

- ▶ Making a commercially-desirable SoC is neither academically nor standard-investor sexy! No AI. Boring. zzzz
- ▶ Luckily there is an anonymous sponsor who needs an SoC that doesn't exist (who knows the commercial benefits of Libre)
- ▶ Shakti Group know the benefits (cost, sovereignty) of a Libre Mobile-Class SoC as well (No spying on India citizens!)
- ▶ A Libre GPU, even a modest performer (100MT/s etc.) is the biggest technical risk/unknown, besides DDR3/4. (fall-back is GC800. Do please help with a Libre GPU!)
- ▶ DDR3/4 and eMMC are the main high-risk interfaces (there are fall-back strategies in place)
- ▶ Ultimately the strategy is all about cost reduction vs risk mitigation, with Libre/Ethical prioritised over "convenience"

The end

Thank you

Questions?

- ▶ Contact: lkcl@lkcl.net
- ▶ http://libre-riscv.org/shakti/m_class/