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Why Apple Wants Intrinsity

Low-Power ARM-Compatible Cores Are Ideal for iPhones and iPads

By Tom R. Halfhill {4/26/10-02}

Apple's stealthy acquisition of Intrinsity is the latest strategic move toward becoming a fully integrated consumer-electronics company. To differentiate its products and justify their higher prices, Apple must do more than wrap trend-setting industrial design and slick system software around other suppliers' standard parts. By developing custom SoCs and embedded-processor cores, Apple is assuming more risk, but the potential payoffs are great: less dependence on third-party suppliers, greater differentiation, higher retail prices, and richer profit margins.

That's a summary of the long-term strategy we analyzed in more depth almost a year ago, after *The Wall Street Journal* reported—with some surprise—that Apple was hiring more chip designers. (See *MPR 5/26/09-01*, "Why Apple Feels Chipper.")

Now, Apple is absorbing Intrinsity, a small Austin-based company that sells embedded-processor cores, circuit-design tools, design services, and innovative intellectual property (IP). *Microprocessor Report* has been covering Intrinsity for ten years—or even longer, counting the company's earlier incarnations as EVSX and Exponential Technologies. In our most recent article, we analyzed Intrinsity's Hummingbird core, a faster but fully compatible implementation of the ARM Cortex-A8. Samsung is using Hummingbird in applications processors for smartphones, probably including a future iPhone. (See *MPR 7/27/09-01*, "Hot-Rodding the Cortex-A8.")

Although neither Apple nor Intrinsity will comment, *MPR* learned that Apple is paying about $121 million for Intrinsity. That's much less money than the $278 million that Apple paid in 2008 to buy P.A. Semi, another embedded-processor company. However, P.A. Semi was a larger organization, with a fabless-semiconductor business model. Intrinsity started life as a fabless semiconductor company but was unable to breach the market with its MIPS-compatible standard-part processors. In 2004, Intrinsity turned away from the chip business, changed management, downsized, and focused on selling its unique Fast14 circuit technology as licensable IP. (See *MPR 1/10/05-02*, "Intrinsity Takes Its IP on the Road.")

For Apple, a company with an astonishing $41.7 billion of cash in the bank, $121 million is pocket change. *MPR* believes the Intrinsity acquisition buys four things, well worth the money: Fast14 technology; exclusive access—or, at least, early access—to Intrinsity's processor cores; a skilled processor-design team with expertise in balancing low power and high performance; and a multigigahertz Fast14 implementation of ARM's Cortex-A9 dual-core processor.

That last item, in development for more than a year, could figure prominently in Apple's plans for future iPhones, iPads, and other consumer gadgets.

Dual-Core Pocket Rocket

In our report about Hummingbird last year, we hinted that Intrinsity might develop a similarly hot-rodded implementation of ARM's dual-core Cortex-A9. Like Hummingbird, the new processor will be fully compatible with the ARM processor on which it's based. Intrinsity's version of the Cortex-A9 will be the third ARM-compatible core developed by the company. The first was the Cortex-R4X, which we covered in 2007. (See *MPR 9/24/07-01*, "Cortex-R4X: Extreme Makeover.")

Intrinsity doesn't try to improve on the microarchitectures of ARM's processors. Indeed, Intrinsity's designers cannot legally alter the microarchitectures unless the customer has an ARM architectural license, because Intrinsity lacks such a license. Companies with an architectural license can create a completely original microarchitecture, as long as it remains backward compatible with an ARM instruction-set architecture (ISA).

Two examples of companies that have bought ARM architectural licenses and have created original designs are Marvell and Qualcomm. Marvell created the first ARM-compatible processor with out-of-order instruction execution. Qualcomm created a similarly sophisticated ARM-compatible design for its cellular applications processors. (See *MPR 5/23/05-01*, "Marvell Puts ARM Out of Order," and *MPR 3/22/10-01*, "Snapdragon Success.")

MPR believes Apple has an ARM architectural license (in addition to ARM core licenses). If so, Intrinsity's designers will have much more freedom after joining Apple. In the past, Intrinsity has been limited to implementing the most critical parts of an ARM core in Intrinsity's proprietary Fast14 domino logic and optimized static logic, along with other tweaks. The result is a processor core that's fully compatible with its ARM counterpart while delivering higher performance—without a severe power-consumption penalty. With the additional freedom to customize the microarchitecture, Intrinsity's designers could achieve even more.

Intrinsity Provides Stopgap Solution

Of course, there are disadvantages to creating a custom microarchitecture. It's a much more expensive project that adds a year or more to the design cycle, requires new test suites, and may require new software-development tools. Marvell and Qualcomm labored for years on their custom ARM projects.

Nevertheless, *MPR* believes that Apple is developing a custom ARM microarchitecture. While that project is underway, we believe Apple will use Intrinsity's ARM-compatible cores as an interim solution.

Even without custom microarchitectures, Intrinsity's ARM cores are ideal for mobile consumer electronics. They're fast, power efficient, and compatible with the industry's most popular 32-bit embedded-processor architecture. With relatively little effort, SoC developers can drop an Intrinsity core into a chip design already based on the ARM Cortex-R4 or Cortex-A8. (*MPR* has covered Intrinsity's technology extensively in previous articles; see the "For More Information" box.)

If Intrinsity has indeed developed a Fast14 implementation of ARM's dual-core Cortex-A9, the maximum clock speed should exceed 2.0GHz in a current CMOS fabrication process. This processor would easily surpass the performance of the single-core Cortex-A8 and Hummingbird. The dual-core Cortex-A9 clone—let's call it Hummingbird-II—would most likely appear in an SoC designed by Apple and manufactured by Samsung for future iPhones and iPads.

To save power, Apple may choose to run Hummingbird-II slower than 2.0GHz in an iPhone. The iPad has a larger battery, better cooling, and will probably attract larger apps, so higher performance will be both practical and desirable. (According to independent tear-downs, the iPad has a 24.8 watt-hour battery, vs. 4.51 watt-hours in the iPhone 3GS.)

But, eventually, even the iPhone will need this level of performance. This summer, Apple plans to release iPhone OS 4.0—which, for the first time, allows multitasking with third-party apps. The iPad will get the new operating system too. Over time, these mobile platforms will continue encroaching on the application space of traditional personal computers.

Does the iPad Use Hummingbird-I?

There is wide speculation that Apple is using Intrinsity's Hummingbird-I in the iPad's A4 chip. The 1.0GHz A4 is the iPad's main applications processor, the equivalent of the Samsung S5PC100 chip in the iPhone 3GS. (According to die photos by Chipworks, Apple's internal part numbers are APL0398 for the iPad chip and APL0298 for the iPhone 3GS chip.) Apple won't confirm or deny the Hummingbird rumor, other than to say that the A4 is indeed a homegrown Apple design.

Under normal circumstances, Apple's design team would have lacked enough time to use Hummingbird-I in the A4. Intrinsity shipped the core around July 2009, and the iPad made its much-ballyhooed public debut eight months later, on April 3, 2010. Usually, a complex SoC, like the A4, requires at least 12 to 18 months to develop, verify, and manufacture in volume. To finish the A4 in time for the iPad's launch, it would seem that Apple must have used a conventional ARM Cortex-A8.

However, Intrinsity claims that developers can drop its cores into an SoC design in as few as four months. The hot-rodded cores are bit-compatible, cycle-accurate implementations of their ARM counterparts. Integration is even easier if the target fabrication process is Common Platform 45nm-LP, because Intrinsity optimized Hummingbird-I for that process. Note that Samsung is using the same process to manufacture Hummingbird applications processors for smartphones. (Samsung is a member of the Common Platform technology alliance.)

Apple has been using Samsung's foundry services for years. According to a preliminary tear-down by Chipworks, Samsung is fabricating the Apple A4 chip in a 45nm nine-layer-metal process (eight copper, one aluminum). Chipworks measured the die at 7.3 × 7.3mm ($53.3mm^2$). Samsung also supplies 2GB of SDRAM and up to 64GB of flash memory in the iPad.

So it's possible that Apple's A4 chip does use Intrinsity's Hummingbird-I, if Apple moved quickly and targeted

Common Platform 45nm-LP at Samsung. And, if Intrinsity finished the dual-core Hummingbird-II last year, an even more-powerful chip could conceivably appear in a new Apple product shipping before 2011.

ARM vs. x86

Apple's acquisition of Intrinsity lends weight to the hypothesis that Apple is betting on the ARM microprocessor architecture for mobile computing devices smaller than Macintosh notebooks (i.e., smartphones and tablets). After all, the last three processor cores that Intrinsity has developed are implementations of the ARM architecture.

Don't jump to conclusions, however. Intrinsity's Fast14 technology is applicable to any microprocessor—even graphics processors. Intrinsity has designed a PowerPC-compatible core for Applied Micro (see *MPR 7/23/07-01*, "AMCC's Titan Core"), has licensed Fast14 technology to ATI (before that graphics-processor vendor was acquired by AMD), and designed its own MIPS-compatible chips when operating as a fabless-semiconductor company. So Intrinsity's recent history with ARM doesn't preclude Apple from using Fast14 with other CPU architectures.

In theory, Apple could even apply Fast14 technology to an x86-compatible design, if software compatibility with the x86-based Mac OS is important for a future product. Of course, the hitch is that Apple would need to design or license an x86-compatible processor core. Intel is reluctant to license the x86 architecture for that purpose, and no one else has a high-performance licensable x86 core. Although last year Intel announced a collaboration with TSMC to encourage development of Atom-based SoCs, nothing has emerged so far. (See *MPR 3/30/09-01*, "Intel Will Customize Atom.")

Keep in mind that the engineers Apple inherited with the P.A. Semi acquisition are equally adept with multiple CPU architectures. Some of those engineers worked on the Alpha and StrongARM processors while at DEC in the 1990s, then moved to PowerPC when P.A. Semi formed. Although some of those P.A. Semi engineers (including cofounder Dan Dobberpuhl) have left Apple since the acquisition, others remain. And, as *The Wall Street Journal* reported last year, Apple has been hiring chip designers and project leaders, in addition to acquiring other talent through acquisitions.

Apple has been using custom chips since the 1980s, so chip design isn't a radically new direction for the company. All large consumer-electronics companies either design their own custom chips or collaborate closely with development partners in their design.

Maturing Technology Enables Tablets

Tablet computers have been imagined since the 1960s, whiteboarded by engineers since the 1970s, prototyped since the 1980s, and sold since the 1990s. For the most part, they have failed to catch on.

To make tablets practical, five technologies had to mature: lightweight rechargeable batteries with high energy density; low-power microprocessors with enough performance to run complex software; flat, lightweight screens with pen or touch sensitivity; sophisticated graphical user interfaces; and pervasive broadband wireless networking.

Although none of those technologies has reached its zenith, they're finally coalescing and attaining critical mass. With the iPad, Apple is adding its usual extra elements: a superlative user interface, trendy industrial design, cultural caché, and unmatched marketing hype. Having a well-established developer community and an App Store with 150,000 programs doesn't hurt, either.

To revive an industry term from the 1980s, Apple is "legitimizing" tablet computers, much as IBM legitimized personal computers with its first PC in 1981. IBM was years late to the party, but set a standard that soon dominated the market. Sometimes it's better to be influential than early. Apple's iPod wasn't the first digital-audio player, but the same combination of elements helped it storm the market. Ditto for the iPhone, which wasn't the first smartphone. The iPad is poised to repeat that success.

This time, however, Apple will encounter more competition. The buzz surrounding the iPad is luring many companies into making another run at tablet computers. One much-anticipated contender is Hewlett-Packard's Slate, which hopes to win devotees by including features that Apple

The main applications processor in the iPad is an Apple-designed SoC, called the A4. It's based on a 1.0GHz ARM-compatible processor core—either a conventional ARM Cortex-A8 or Intrinsity's souped-up Hummingbird core, which is fully compatible with the Cortex-A8. [Photo: Courtesy of Apple]

For More Information

Previous *Microprocessor Report* articles about Intrinsity:
MPR 6/5/00-04, "EVSX Changes Name to Intrinsity."
MPR 8/13/01-02, "Intrinsity's Dynamic Designs."
MPR 6/10/02-01, "Two GHz to Go."
MPR 5/13/02-01, "Intrinsity Arrays 2GHz Adaptive Matrix."
MPR 1/6/03-01, "Intrinsity Delivers On Its Promise."
MPR 2/18/03-03, "Embedded Processors Chill in 2002."
MPR 2/18/03-05, "Extremely High Performance."
MPR 5/27/03-03, "Update on Intrinsity Fast Products."
MPR 2/9/04-07, "Embedded CPUs Do More, Run Faster."
MPR 2/9/04-15, "Extreme CPUs Defy Conventions."
MPR 2/23/04-01, "Intrinsity Licenses Fast14 to ATI."
MPR 1/10/05-02, "Intrinsity Takes Its IP on the Road."
MPR 7/23/07-01, "AMCC's Titan Core."
MPR 9/24/07-01, "Cortex-R4X: Extreme Makeover."
MPR 9/24/07-02, "Intrinsity Turns a Corner."
MPR 7/27/09-01, "Hot-Rodding the ARM Cortex-A8."

left out. (Examples: USB ports, an SD card slot, a camera, and a webcam.) The industry was a little late at jumping on the iPod and iPhone bandwagons and is determined not to repeat the mistake.

Apple Evolves With the Industry

The iPad is more evidence that the definition of "personal computer" is radically changing. In the 1980s, it meant a computer for every person. Now it means a computer that's easily carried and used anywhere by a person. Bulky desktop PCs are looking more and more like the spiritual descendants of yesterday's mainframes.

This paradigm shift is reshaping the entire industry. It explains why companies whose business models revolve around conventional PCs are losing their positions or scrambling to adapt. So far, no personal computer company is adapting as well as Apple—which, in fact, no longer calls itself a computer company.

Indeed, Apple is even abandoning the traditionally open software-development model fostered by the original Apple I and Apple II personal computers. The iPhone, iPod Touch, and iPad are all but closed to third-party developers who don't use Apple's software-development kit (SDK) and the Apple-filtered App Store. Apple sells the SDK (which runs only on a Mac) and reaps a share of revenue from each third-party app sold.

Apple's tight control over its mobile platforms closely resembles the business model that Nintendo introduced to home videogame consoles in the 1980s. Nintendo rigidly controlled the third-party games developed for the Nintendo Entertainment System (NES) and extracted a share of revenue from them, as well.

As the iPhone, and particularly the iPad, scale upward in capability, they will gradually encroach on the territory of the Macintosh, which remains more open to developers. The greater revenue potential of a fully closed system may encourage Apple to accelerate that encroachment, even beyond the market's general migration toward mobile platforms.

Intrinsity adds another ingredient to the mix. Now, for mobile devices, Apple has almost total control over the design of the vital low-level hardware—the microprocessor chips. In addition, Apple gains high-performance ARM-compatible processor cores and the experienced engineers needed to continue its evolution as an industry-leading consumer-electronics company. ◇