Two decades of “plug and play”

How USB became the most successful interface in the history of computing

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Growing frustration of PC users

Today the least tech-savvy consumer can attach printers, scanners, cameras and other peripheral devices to PCs easily, simply by plugging them into the ubiquitous USB (Universal Serial Bus) ports found on every platform. But in the early 1990s, things were anything but "plug and play."

The back of the PC told the story. There were ports of different sizes and shapes, each dedicated to a single type of peripheral—one for a mouse or keyboard, another for a printer, others types for joysticks, modems and audio devices. They were all shaped differently and used unique protocols. These ports also limited the number of devices users could connect to their PCs; to add a second printer, for instance, users had to remove the first. And there was no place to plug in devices such as scanners, cameras, and external storage drives.

"If you wanted to connect a more advanced peripheral device, such as a scanner, you had to open up the PC and plug in a SCSI card, and there was a lot of end user confusion about how to do this," says Bala Cadambi, who was an I/O Architecture Manager at Intel at the time. "A card might come with the scanner, or you might have to purchase it. You'd disconnect power, open the desktop computer and plug in the card, but then you'd have to configure it in the system, and this was very difficult to do. And it didn't usually work the first time you tried; often you'd find conflicts so that if one device worked, another stopped working, and you had to figure out how to get back the functionality you lost."

> *About one-third of scanners purchased were being returned because customers could not get them configured.*

Customers were flooding call centers with questions—and venting their frustrations over trying and failing to attach devices to their PCs. "About one-third of scanners purchased were being returned because customers just could not get them configured," Cadambi recalls. Not only was this a huge problem for the retailers who handled the returns, but it meant that useful devices such as scanners were not widely adopted. More important, innovation in peripheral devices was limited by lack of usability.

There had to be a better way.

The USB solution

Intel facilitates search for a solution

Within the Intel Architecture Labs, the company's central R&D organization, in 1992 several engineers began exploring how to simplify the process of adding devices to PCs. And they were conversing with their counterparts across the industry, who also were keen to tackle the challenge. "The industry as a whole recognized that it had a big problem that needed to

be solved," says Jim Pappas, who at the time was an engineering manager at DEC and was part of those conversations.

"Intel was uniquely positioned because we're the common element across many different platform and device OEMs," said Brad Saunders, an Intel architect who became chair of the USB Implementers Forum. "We helped to facilitate conversations about what needed to be done in this space and offered our contributions."

Soon a small group of companies, spurred by Intel, joined forces to create a solution: the Universal Serial Bus (USB). This specification, introduced in 1996 and ubiquitous in PCs and devices today, enables users to connect a variety of peripherals, from printers and mobile phones to scanners and storage drives, using a single, standardized interface socket. USB enables "hot swapping"—connecting and disconnecting devices without the need to turn off or reboot the computer, a process that came to be known as "plug and play." Setup is simple and doesn't require the installation of manufacturer-specific drivers for peripheral devices.

With the development of USB, consumers finally had an easy solution for connecting peripheral devices. The popularity of subsequent "plug and play" solutions can be attributed to the success of USB's simple interface.

Developing USB: The early days

A collaborative effort

Jim Pappas was recruited from DEC to Intel and asked to program manage the USB industry effort. Intel believed that making it easier to expand and configure platforms with external peripherals would advance the computing industry by creating new usages for PCs. It also would spark innovation in peripherals, enabling that segment of the industry to thrive.

"The influence and trust Intel had was built on the promise of our platform roadmap and our ability to build collaboration," says Cadambi, who managed the USB development team. "And there was a recognition that companies didn't mind healthy competition around standardized technology, because everybody comes out ahead, as the market grows and there's opportunity for innovation." Put simply, it's better to have a small slice of a huge pie than a huge slice of a small pie.

A handful of industry companies joined Intel in the core development of USB, including Compaq Computer Corporation, DEC, IBM, Microsoft, NEC and Northern Telecom.

Keeping it simple

In leading the core USB development team, there was one key goal: to keep the interface simple. "People who knew we were developing USB wanted to add lots of things to the interface," Pappas recalls. "But we had an extremely strong view of keeping the architecture simple. And that was the most complex part of the project. We sometimes talked about the 'Christmas tree effect' – everyone felt that if they could add their favorite ornament, the tree would be perfect. But at some point, the branches droop and the tree falls down. Managing the Christmas tree effect was critical to USB's success."

"You couldn't keep adding features without making USB unviable in terms of cost," adds Cadambi. "More important, simplicity makes it easier to establish a standard. Once you start adding features to make the technology rich in options, it compromises interoperability and degrades the end user's experience of the system."

While the team focused on "keeping it simple," the USB interface nevertheless enabled complex use cases, thanks to the design's creativity.

> *Adding too many optional features would compromise interoperability and the end user experience.*

Key design decisions

The team agreed that the new interface would have to be inexpensive, and it should have a lot of bandwidth (in those days, 12 megabits per second (Mbps)—the highest speed delivered by the first version of USB—was considered "a lot"). The technology also must be plug-and-play, with no need for consumers to open their PCs to install and configure add-on cards; rather, devices would be configured with little user intervention.

The USB developers also wanted the interface to power peripherals without the need for "wall warts" or additional external adapters; power would be part of the connectivity model. That early decision was fundamental, according to Pappas. "At the time, no other widely used port was providing power," he says. "In retrospect, that was one of the most impactful decisions that we made, because it became much easier to attach a wide variety of devices to PCs with a single cable. Now small devices could get their power from the PC; they didn't have to be plugged into the wall, and that was a really big deal."

To address the growing demand for new types of peripherals, the team made another key decision: to extend the number of ports through hubs, which could be manufactured easily and at a low cost. "It's not that we expected PCs to be built with just one port, but even if there was just one port, by using hubs you could extend the number of peripherals you could attach," says Pappas. He says that this decision not only improved ease of use but led to an "explosion of peripheral devices" that boosted the PC industry.

The USB architecture also encouraged the development of new devices. "We used a tree topology where the PC was at the root of the tree," says Pappas. "This meant that every device was managed by the PC, so devices had a tremendous amount of platform technology resources they could take advantage of, and that meant the devices themselves could be simple."

Finally, each iteration of USB would be designed to be backwards compatible. This means that devices supporting earlier versions of USB technology can work with PCs or other host devices that support later versions of USB.

Managing costs

To ensure the success of USB, the team considered the cost of developing USB-compliant devices. For instance, to ensure that Microsoft would adopt USB for the next version of its mouse—which would be critical to the success of the interface—the team had to ensure that the USB interface would not drive up the cost of the mouse. When Pappas mentioned to Betsy Kim, the engineering manager of the Microsoft mouse team, that the USB team wanted the new interface to deliver at least 5 megabits per second, she told him that the mouse would require a shielded cable to accommodate that speed. At four cents per foot, shielding a 6-foot mouse cable would add 24 cents to the cost of a mouse, which would make it uncompetitive. For Microsoft, this was a deal breaker.

A two-speed solution ensured that USB would not drive up the cost of embedding the technology into Microsoft's mouse, which was critical to success.

A two-speed solution

To address the challenge, the USB team developed a two-speed solution: In slow-speed mode, USB would operate at 1.5 Mbps to accommodate low-speed devices such as the mouse, eliminating the need for shielded cables. Devices needing more power would operate at 12 Mbps. "The decision to save the mouse grounded our cost structure, and I think it enabled USB to reach the level of billions of units that have reached the market," says Pappas. "I think it was one of the most important decisions we ever made."

Embedding USB in Intel Chipsets

Intel knew that to ensure widespread adoption of USB by platform and device manufacturers (and ultimately, by consumers), the company would have to integrate the technology in its own chipsets. To do that, the team would need to keep costs down. "When we defined USB, we had to figure out what host controller functionality could be put into the next generation chipset and still enable us to offer it at the same price point as the previous chipset," says Cadambi. "The most liberal budget we were allowed was 10,000 gates on a chip. So we had to work within that budget, such that system software working with the host controller hardware could support the full range of peripherals (including as yet uninvented peripherals) and associated data types. This required many tradeoffs in the hardware and software partitioning."

Adding to these constraints was the challenge of delivering the new interface in high volume. "We had to make the hardware and software integration line up with PC industry development and delivery cycles," says Cadambi. "And the cycle to integrate and test USB was pretty demanding, given the diversity of people that had to come together across the industry."

The team overcame these challenges, and in the spring of 1996, Intel began integrating USB into its chipsets.

The first versions of the spec

Intel developed the initial internal draft of the USB specification in 1994. There were many revisions made to this straw man document in collaboration with the core group of companies and integrating feedback from industry-wide reviews. Cadambi recalls that "the first conference in September 1995, held at the Fairmont Hotel in San Jose, had standing room only."

In 1998, USB reached a critical turning point. Until then, the technology had not been integrated into PC operating systems. But in June 1998, a draft version of the USB 1.1 spec was supported in the Windows 98 operating system—the dominant OS worldwide—which began shipping that month. From this point forward, the number of USB devices on the market began to proliferate.

The first published version of USB (Version 1.1) was released in September 1998, with two speeds: 1.5 Mbps (Low-Speed) and 12 Mbps (Full Speed). To educate developers, the USB team held technical meetings on various aspects of the new technology, from signaling and bandwidth to the protocol and the various device classes that could leverage USB.

On the road to building an ecosystem

Because USB touched on so many parts of the industry, both hardware and software, the team would have to garner support from a broad range of players. Pappas and his colleagues traveled the world, visiting dozens of companies to discuss the potential of USB and gain their agreement to design to the new interface.

One trip took them to Japan, to persuade the leading camera manufacturers to adopt the new interface. At the time, digital photography was one of the most important potential applications for PCs, along with digital music. Pappas brought with him a digital camera that had a serial port for connecting to a PC, and a PowerPoint slide that compared the amount of time it would take to upload photos using the serial port (about two hours) versus USB (about 12 minutes). The slide also noted that traditional film could be processed at a one-hour facility in half the time it took to upload from a digital version from the serial port. "It was a pretty high-impact slide," says Pappas, and a year or so later, all of the Japanese manufacturers began rolling out new USB-enabled cameras.

Engaging the Industry: The USB Implementers Forum

Accelerating adoption

With the first draft specification published, in 1995 the core group of companies that developed USB formed the non-profit USB Implementers Forum (USB-IF) to support and accelerate market and consumer adoption of USB-compliant peripherals. "We wanted to market the technology and engage the industry to a point where they could start producing products," says Pappas. "Having a forum to join was a good way to get the industry engaged."

After its formation in 1995, the USB-IF grew quickly. "I think we went from zero to 160 companies in the first month or so, and hundreds more were added over the next few months," says Pappas, who became the first chairman of the organization, a position he held until 1997. "Then USB became an unstoppable force in the industry. Everyone was building USB-capable products in order to stay competitive, and companies asking questions about the USB-IF immediately joined. And we had a tremendous onslaught of peripherals being delivered."

> *USB quickly became an unstoppable force in the industry. Everyone was building USB products in order to stay competitive.*

As of November 2014, the USB-IF had more than 800 member companies, and it had helped to bring hundreds of USB-compliant products to market.

Supporting developers and end users

Free access to USB-IF specs

The USB-IF makes its specifications and adopters agreements available for free download by anyone worldwide. "Whether I'm an inventor working in my garage or a huge corporation, getting the information to deploy the USB technology is very easy," says Jeff Ravencraft, who became President and Chief Operating Officer of USB-IF after his retirement from Intel in 2011. "And because USB is an open interface, anyone can build USB devices," Cadambi

adds. “You don’t have to approach a PC manufacturer to ask ‘can you add this function?’ You can design your product and sell it directly to the retail market.”

The USB-IF Adopters Agreements spell out a reciprocal, RAND-Z (reasonable and non-discriminatory, zero royalty) licensing obligation. Essentially, they state that anyone who executes an Adopters Agreement for USB is required to grant a license on RAND-Z terms to all other Adopters and to Promoters, and receives a reciprocal license from them. “This establishes a baseline for how Adopters are going to do business with each other, when it comes to licensing their intellectual property that’s required to implement the spec,” says Ravencraft. This arrangement gives companies the confidence that they will have access to the intellectual property they need to develop their products, eliminating a key barrier to adopting USB.

A range of device classes

Prior to USB, devices as simple as a mouse often required a unique software driver. The USB-IF eliminated this inconvenience by allowing for the development of common standardized device classes with associated device drivers. “One of the reasons that USB is so successful is that the software for connecting all the different device types is usually pre-built into the platform,” says Saunders. “That’s because the USB-IF has developed and published a set of device class specifications which define how the devices behave from a software perspective, and operating system vendors have embraced these specifications and built their software around them. The result is that all the devices can simply connect and work. So the USB-IF is a key market-enabling organization in ensuring that the user experience is consistent and delivering the plug-and-play promise to consumers.”

> *Operating system vendors have built their software around the USB-IF’s device class definitions. The result is that USB devices are plug-and-play.*

The USB-IF focused initially on device class definitions for simple technologies such as mice, keyboards and other human interface devices (HIDs), adding more complex device classes over time. Following is a partial list of the device classes the USB-IF has defined:

Audio	IrDA	Printer
Audio/video	Mass storage	Smart card
Communications Device	Media transfer protocol	Test & measurement
Content security	Monitor	Video
HID	Personal healthcare	
Imaging	Physical interface devices	

Collaboration with USB Promoter Groups

Starting with the development of the USB 2.0 specification, the process to develop next generation USB specifications was formalized within specification-specific industry promoter groups: The USB 2.0 Promoter Group was formed in 1999 to support development of the USB 2.0 Specification, the Wireless USB Promoter Group was established in 2004 for the Wireless USB Specification, and the USB 3.0 Promoter Group was formed in 2007 to support USB 3.0.

In essence, the USB Promoter Groups develop the foundational specifications for each USB generation, while the USB-IF focuses on industry outreach, product certification, and ancillary specification development as well as market support and promotional activities.

From specs to store shelves: Five key areas of focus

Many standards organizations develop specifications but do not engage in the many other activities required to make the specs succeed, from advertising and promotion to education and the creation of developer tools. “Writing a technology spec is one thing, but translating that piece of paper into a product that sits on a shelf at Costco is a huge undertaking,” says Ravencraft. To translate specs into successful products, The USB-IF engaged in a broad range of activities, in five key areas.

1. Compliance testing and logo licensing

One of the most important areas of focus of the USB-IF, and a key benefit of the annual membership fee, is free compliance and certification testing and logo licensing. This represents a substantial cost savings for members.[1]

The USB-IF compliance program is one of the most comprehensive in the industry. The USB-IF holds quarterly compliance workshops where members can bring their products and get them certified at no charge. Members whose products don’t pass the test can access the on-site experts and other industry players in attendance to help resolve their issues and achieve compliance. “There’s a huge learning curve that companies are able to participate in, just by coming to the workshops,” says Ravencraft.

Non-members can have their products tested at a third party certified test facility, at their own expense. This access to compliance testing ensures that any company which develops a USB peripheral has a means of ensuring that its products adhere to USB-IF specifications and thus will be interoperable.

Products that achieve certification may be authorized to display the USB logo, but this requires that a company have a valid USB-IF Trademark License Agreement (TLA) on file. The license administration fee is waived for members. Vendor IDs (VIDs) are free to members as well, but both the TLA and VID must be purchased by non-members.

> *Writing a technology spec is one thing, but translating the spec into a product that sits on a shelf at Costco is a huge undertaking.*

2. Educating through events

The USB-IF provides extensive education to the industry, with a heavy focus on developers. “We want to enable developers to quickly deploy the next generation of USB technology,” says Ravencraft. The organization hosts two-day events during which industry participants can attend technical reviews and Q&A sessions. The USB-IF also participates in all the major industry events, such as the Intel Developer Forum (IDF), Consumer Electronics Show (CES) and Computex. In addition to leading technical sessions during events, the USB-IF does outreach to the press and analysts to keep them informed about the latest developments in USB.

[1] More detailed information about the cost and benefits of USB-IF membership is available at https://www.usb.org/members_landing

Throughout the years, USB has been widely promoted at industry events.

3. The Device Working Group

The Device Working Group within the USB-IF, which meets regularly, is the venue in which most of the device class specifications are defined and compliance and certification programs developed. Developer education is also provided through the Group. Members are allowed to participate in the Group's meetings and contribute to defining specifications.

4. Advertising and marketing

The USB-IF has a robust marketing and advertising program for promoting the USB brands to the industry and consumers. "We think a key reason why companies want to get their products certified by us is that they can benefit from the free marketing and advertising we provide," says Ravencraft. Members can participate in many USB-IF marketing initiatives, from retail newsletters to store end caps, events and featured products.

Retail store end cap featuring USB products.

The USB-IF runs print ads in industry trade magazines and participates in advertising at industry events. To reach consumers, the organization maintains a retail sales program in North America to educate the retail salespeople at major electronics stores, educating them about the features and benefits of USB technology for their customers. The USB-IF also advertises directly to consumers through venues such as in-flight magazines, which gives the organization a global reach.

5. Protecting the USB brands

The USB-IF works actively to defend the integrity and maintain the value of USB brands. "We have different brands that we have trademarked around the world, and we vigorously protect those marks," says Ravencraft. Among other things, that involves training US Customs personnel and international customs organizations to identify products displaying unauthorized or counterfeit USB trademarks. The USB-IF also has a secret shopper

program, to help ensure the integrity and prevent misuse of USB-IF Certified logos. And it educates corporate buyers about the features and benefits of certification, and works with them to recommend or require certified products, if possible.

These efforts to protect the USB brands add value to the USB-IF membership. And they benefit retail and corporate buyers, who can look for a USB logo when making purchases, knowing that it guarantees the products are legitimate, have been tested and found to be compliant with the standard, and are interoperable.

Cooperation with global organizations

In addition to the focus areas highlighted above, the USB-IF engages actively with formal international and regional standards bodies such as the International Electrotechnical Commission (IEC) and CENELEC, the European Committee for Electrotechnical Standardization, gaining recognition for USB-IF specifications within regional standards and publication of the specs as IEC international standards. And the organization is constantly expanding its activities in response to advances in technology, such as the emergence of embedded systems, to ensure that USB remains relevant. For instance, the USB-IF works closely with automakers in the US, Europe and Japan to enable connectivity inside the car.

Advancing the technology: USB 2.0 (Hi-Speed USB)

Full Speed USB (Version 1.1) had a rich set of hardware and software capabilities, but it needed more performance headroom. One of the key motivators for revising the specification was to meet the need for faster storage.

“People discovered that USB had uses beyond the keyboard and mouse, and the first interesting usage that came along was storage,” says Bob Dunstan, an Intel Architect. “So users started attaching storage to their PCs.” For early storage solutions, the USB 1.1 data rate of 12 mbps was sufficient, but the need for more storage space soon created a need for more speed. “At a rate of 12 megabytes a second, to say that transferring data was painfully slow would be an understatement,” says Dunstan.

40x the speed of USB 1.1

To improve upon the data rates of USB 1.1, USB 2.0 (Hi-Speed USB) was released in April 2000. This new version of the specification delivered signaling rates of up to 480 Mbps—as much as 40 times faster than Full Speed USB.

Pappas led the team that developed USB 2.0. If his mantra for delivering the first version of the spec was “keep it simple,” the slogan for version 2.0 was “keep your focus.” The team originally developed a list of ten reasons why a new version of USB was needed, but Pappas kept pushing back, insisting that the team distill the list down to two or three key applications the spec would enable.

Focusing on three applications

Pappas knew that USB 2.0 could support all the applications on the list, but he also knew that focusing on too many initially could stall development of the new spec. “Having a laundry list of applications can actually hurt the effort,” says Pappas. “With each new application you want to add, you will find not just supporters but ‘distracters’ who want to dive into the implementation details. And the spec may not get developed, because every shortcoming becomes a reason not to do it. By contrast, if you’re focused on just a few

applications that you can deliver well, you increase the odds of success. And once the technology is successful and becomes ubiquitous, you can start adding other applications."

Ultimately the team zeroed in on three applications—digital storage, digital imaging and communications—and this was critical in enabling USB 2.0 to ship. Over time, USB 2.0 expanded to include many additional applications, but it was the team's focus that enabled the technology to become a commercial success.

Charging devices via USB

As users began to adopt USB 2.0, they realized that the technology could be used for more than moving data between their mobile phones and computers. "Users realized they already had the USB connection for storage," says Dunstan. "They asked 'why don't we use the 2.5 watts of power to charge our cell phones?" Mobile phone manufacturers also wanted to charge batteries at rates higher than 2.5 watts (which USB 2.0 delivered).

To meet the growing demand for charging devices, the USB team developed the USB Battery Charging Specification, which was published in March 2007 and based on the USB 2.0 data connection. Under the new spec, the platform would deliver as much as 7.5 watts of power to devices (up to 1.5 amps at 5 volts). "This allowed users to charge their cell phones and other devices that have 6- or 6.5-watt-hour batteries in about an hour, which users considered an acceptable rate at the time," says Dunstan.

Going "green"

Once users realized that USB could be used to charge devices as well as transfer data, they began to view the technology differently. "They saw that they could use the USB connector for multiple things, including going green," says Dunstan.

Proprietary mobile phone chargers from different manufacturers could not be reused across different phones, so many ended up in landfills. "People who joined the green movement realized that every cell phone manufacturer had a different connector for charging," says Dunstan. "Consumer advocacy groups started putting pressure on the cell phone industry and governments to move towards a common charging capability."

> *Mobile phone manufacturer had a different connectors for charging. Consumers started pressuring the industry to move towards a common charging capability.*

USB 2.0 and USB connectors already were widely used to synchronize data from PCs with smartphones, thanks to ease of use and low cost. Since mobile phone manufacturers didn't want to add a second connector to their small devices, it was a logical choice to adopt USB as the common interface standard for charging their phones.

USB recommended as common charging technology

Korea and China recommend USB for mobile phone charging

In 2001, the Korean Telecommunications Technology Association (TTA) developed a voluntary standard for mobile device interfaces that included USB. In 2006, China included USB requirements in a CCSA (China Communications Standards Association) standard for mobile phone charging, and from 2007, all new mobile phones were required to be compliant with the national standard to gain approval for access to the public telecommunication network.

Smartphone industry support and European activity

In 2009, the GSM Association (GSMA), a major industry trade group for mobile phone operators and other companies in the mobile ecosystem as well as organizations in sectors such as healthcare and financial services, announced that USB would be the recommended technology for charging of mobile phones. The same year, the European Commission (EC) persuaded the major manufacturers of smartphones to sign a Memorandum of Understanding (MoU) to voluntarily adopt a common charging interoperability standard based on USB and the Micro-USB connector as the common charging interface for data-enabled smartphones in the EU, effective from January 2011. By the end of 2012, an estimated 90% of new smartphones in the market were compliant with the MoU . The EC and smartphone manufacturers will need to continue cooperation on best approaches to support ongoing commitments to interoperable chargers without stifling innovation that future technology advancements can enable.

Generally, the technology industry prefers voluntary agreements over government-mandated standards and regulations. Intel and other industry members believe that a better approach for supporting innovation and economic activity is for governments to focus on the goals they wish to achieve through regulations and reference industry-led, voluntary global standards that can meet those requirements.

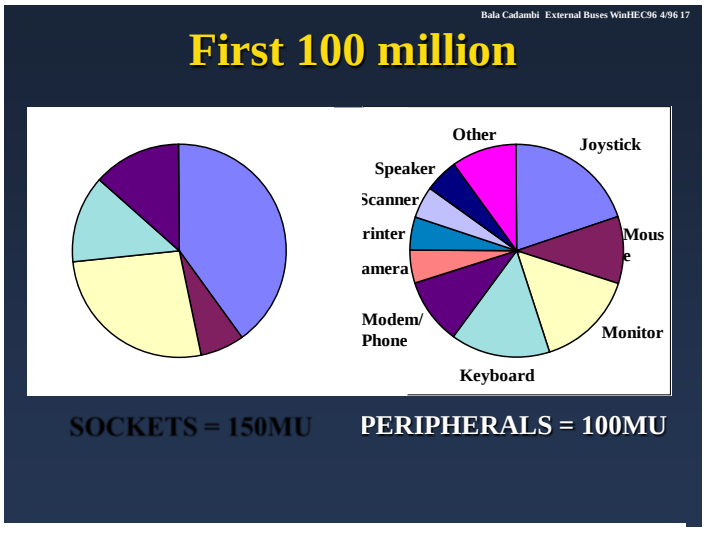
USB recognition by ITU and IEC

With the broad global market adoption of USB 2.0, the technology was embraced by two leading international standards bodies. In October 2009 the International Telecommunication Union (ITU) published Recommendation ITU-T L.1000 which aligning with the GSMA and EC MoU, specifies the use of USB for mobile terminal charging. And in September 2012 the IEC announced the approval of four USB-IF specs as formal international standards IEC 62680-x, including USB 2.0 and the related cables and connector specification; the USB Battery Charging Specification; and the Micro-USB Cables and Connectors Specification.

An enduring success

The Universal Serial Bus has evolved to become the most successful interface in the history of personal computing. But in the early days, it was difficult even for the development team to envision how the new technology would evolve and proliferate. “We never expected that USB would achieve the enormous success we’ve seen, not by any stretch,” says Cadambi. “At the time, we were designing an interface that we thought would last five years.”

If it was difficult for the developers to envision the stunning trajectory of USB, it was even harder for others in the technology community. In 1996, Cadambi and Pappas developed a presentation that included a slide highlighting their vision of the first 100 million units of USB—a figure that seemed wildly ambitious in a year when only about 70 million PCs shipped worldwide. “When we gave this presentation and talked about the first 100 million units, the audience laughed,” says Pappas.



Slide in presentation by Bala Cadambi and Jim Pappas at WinHEC 96, highlighting their ambitious vision for USB. Today more than four billion USB units are shipped annually.

"But we ended up exceeding that 100 million figure by two orders of magnitude."

Over the years, USB specifications have evolved, with each new version improving performance dramatically. The technology has been widely adopted around the world and has driven countless innovations in peripheral devices and applications. Among other things, USB has revolutionized the music and photography industries, bringing professional-level A/V capabilities to consumers, and it has enabled convenient data storage in the form of thumb drivers and larger external hard drives. Business has also benefited from the vast new markets created for USB products. "For technology businesses, USB has provided a great opportunity to participate in a very large pie," says Ravencraft.

Performance of Early USB Versions		
USB version	***Date introduced***	***Speed***
1.0	January 1996	• 1.5 Mbps (Low Speed) and 12 Mbps (Full Speed)
1.1	September 1998	• 1.5 Mbps (Low Speed) and 12 Mbps (Full Speed)
2.0	April 2000	• 1.5 Mbps (Low Speed), 12 Mbps (Full Speed) and 480 Mbps (Hi-Speed) • Hi-Speed is up to 40x faster than Full Speed

USB Comparative Performance for Common Data Transfer Tasks						
USB version	***Song / Picture*** *(4MB)*	***256 Flash*** *(256 MB)*	***USB Flash*** *(1 GB)*	***SD-Movie*** *(6 GB)*	***USB Flash*** *(16 GB)*	***HD Movie*** *(25 GB)*
1.1	5.3 sec	5.7 min	22 min	2.2 hr	5.9 hr	9.3 hr
2.0	0.1 sec	8.5 sec	33 sec	3.3 min	8.9 min	13.9 min

The next two decades

The USB-IF and USB promoter groups plan to continue advancing the technology to ensure the next two decades will be as successful as the first two. The basic USB specifications in place today will be able to scale well into the future, according to Saunders. "We believe that the current architecture design could scale to at least 50 gigs per second, if the need arises and the technology interface needed to drive that fast is available."

> *The basic USB protocols in place today will be able to scale well into the future. We believe the original architecture design could scale to as much as 50 Gbps.*

In addition to scaling performance, the USB-IF has focused on accommodating changing form factors. The developers of USB have responded to ever-thinner mobile phones and devices with new and more compact connectors, such as the Micro USB 2.0 connector, defined in 2007, and the USB Type-C connector, introduced in 2014.

Intel's ongoing commitment

Many of the ideas that spawned USB originated in Intel technology development labs, and over the years Intel has played a key role in advancing and promoting the technology. The extraordinary success of this simple but powerful technology inspires Intel to continue innovating.

Learn more

Read about "SuperSpeed USB and Beyond":

https://www-ssl.intel.com/content/www/us/en/standards/superspeed-usb-and-beyond-article.html

Explore more information about evolving USB standards: www.intel.com/standards

Learn more about USB on Intel's website: www.intel.com/technology/usb/index.htm

Visit the USB Implementers Forum: www.usb.org