

# Extrinsically adaptable systems

or “what are hacker-friendly systems and how we should ask for more”

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## Abstract

Are there qualitative and quantitative traits of system design that contribute to the ability of people to further innovate? We propose that *extrinsic adaptability*, the ability given to secondary parties to change a system to match new requirements not envisioned by the primary provider, is such a trait. “Extrinsic adaptation” encompasses the popular concepts of “workaround”, “fast prototype extension” or “hack”, and extrinsic adaptability is thus a measure of how friendly a system is to tinkering by curious minds. In this report, we give “hackability” or “hacker-friendliness” scientific credentials by formulating and studying a generalization of the concept. During this exercise, we find that system changes by secondary parties fall on a subjective gradient of acceptability, with extrinsic adaptations on one side which confidently preserve existing system features, and invasive modifications on the other side which are perceived to be disruptive to existing system features. Where a change is positioned on this gradient is dependent on how an external observer perceives component boundaries within the changed system. We also find that the existence of objective cost functions can alleviate but not fully eliminate this subjectiveness. The study also enables us to formulate an ethical imperative for system designers to promote extrinsic adaptability.

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# 1 Introduction

Since the turn of the 21st century, powerful market forces are at play to redefine the place of general-purpose computers. Before the last decade, users could define the function of their computing devices separately from form. They could do so by acquiring software, but also by writing their own software, separately from the acquisition of the platform. They could also replace hardware components by alternate devices with the same interface but a different implementation. In contrast, the last decade has then seen the advent of tightly integrated smart terminals and entertainment platforms, whose form and function are bundled by the manufacturer and not separable by the user. These devices have displaced commodity, modular general-purpose platforms. They progressively erase the incentive to educate non-technical audiences about the benefits of carrying out their own innovation.

On the one hand, we could simply acknowledge this evolution as a natural effect of a free market where consumers have decided, through their purchasing power, their preference for pre-programmed fixed functions and corporate control over features. On the other hand, we could also worry about an opportunity loss, that of educating a larger number of individuals to the power of modularity, reuse and adaptability in computing systems. With the end of the “free lunch” ten years ago [4, 5], the industry is struggling to devise new architectures and technical mindsets to answer ever growing computational needs. It seems to us that a large diversity of creative approaches by individuals empowered to innovate will be needed to overcome these challenges.

Meanwhile, the words “empowering to innovate” may seem at first sight to be a wilfull but empty shell. This author is dedicated to give these words a concrete meaning in a scientific context. The general line of research is to investigate the following question: are there qualitative and quantitative traits of system design that clearly contribute to or detract from the ability of people to further innovate?

One specific trait that contributes to innovation is the ability given to secondary parties to perform changes to existing systems, to match requirements not initially envisioned by the primary system provider. We call these changes *extrinsic adaptations*. This is the process that a hobbyist uses when replacing an engine carburetor by another to experiment with a “greener” alternative. It is the process by which many scientists prototype their ideas of optimizations to existing systems. Extrinsic adaptations, and the ability to perform them on existing systems, constitute an essential *instrument to innovation*. The rest of this report thus focuses on how to describe extrinsic adaptations generally, and what properties of systems are favorable to extrinsic adaptations. These questions are important because their answers provide guidelines to systems designers to preserve and promote opportunities to innovate in the future.

We start in sections 2 and 3 by proposing a general definition and a couple of illustrative examples. We then describe in sections 4 to 6 the nature and impact of extrinsic adaptations from the perspective of engineers and users. Strong with this conceptual equipment, we then propose in section 7 some general, quantitative measures of extrinsic adaptability, which we then apply in the specific case of computing systems in section 8. A summary is then provided in section 9.

## 2 The essence of extrinsic adaptation

Any sufficiently complex system is an assembly of components where the specification, provision, integration and exploitation of the components are performed by and under the responsibility of different parties.

When a new party comes in contact with an existing system, they may have new expectations towards this system that were not envisioned by the parties interacting with the system so far. From the time these expectations are phrased into requirements, and until the time where the entire system is changed to match these requirements, a discussion occurs between the parties about whether and how to best evolve the system. During this discussion, a process of gradual change may occur where some components are adapted, and where other components that should be modified are left unchanged for non-technical reasons: money, intellectual property, lost source code, politics, etc.

The study of these change processes is a branch of change management. We focus here on change scenarios where:

- a new requirement on a system is formulated by a secondary party, i.e. not the primary parties providing the system;
- components that should be modified by the primary parties to answer the new requirement are left unmodified;
- instead, the system as a whole is coerced externally by a secondary party into adapting towards the new requirement, possibly in a way judged “less than optimal” by the primary parties.

We call this type of change *extrinsic adaptation*. The term encompasses other terms commonly used in more specific scenarios: “workaround”, “bypass”, “stop-gap measure”, “quick and dirty solution”, “temporary fix”, “hack<sup>1</sup>”, etc.

An extrinsic adaptation exists from the moment a system is modified in this way towards a new requirement. It stops to exist when the primary parties either adopt the change, i.e. extend their vision of the system to include the adaptation as an intrinsic new feature, or adapt the system in a different way towards the same requirement, i.e. perform an alternate, “canonical” adaptation. While the extrinsic adaptation exists, it may (but does not have to) be perceived to be idiosyncratic, somewhat “out of line” from the systems’ overall design guidelines and aesthetics. We illustrate these aspects in fig. 1.

In the rest of this report, we are primarily interested in component boundaries defined by *behavior interfaces* (“black box model”), which specify which signals/actions can influence the component’s behavior and what are its observable effects on its environment. For example, in the hardware domain, this definition maps to physically bounded components, where behavior is defined by the signals entering and leaving the component boundary; in the software domain, it maps to programming interfaces (APIs) and what side effects from the component are observable from the run-time environment’s perspective. Note however that we do not limit our argument to computing systems until section 8.

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<sup>1</sup>using here the friendly meaning of the word “hack”: “a quick job that produces what is needed, but not well.” cf. <http://www.hacker-dictionary.com/terms/hack>.

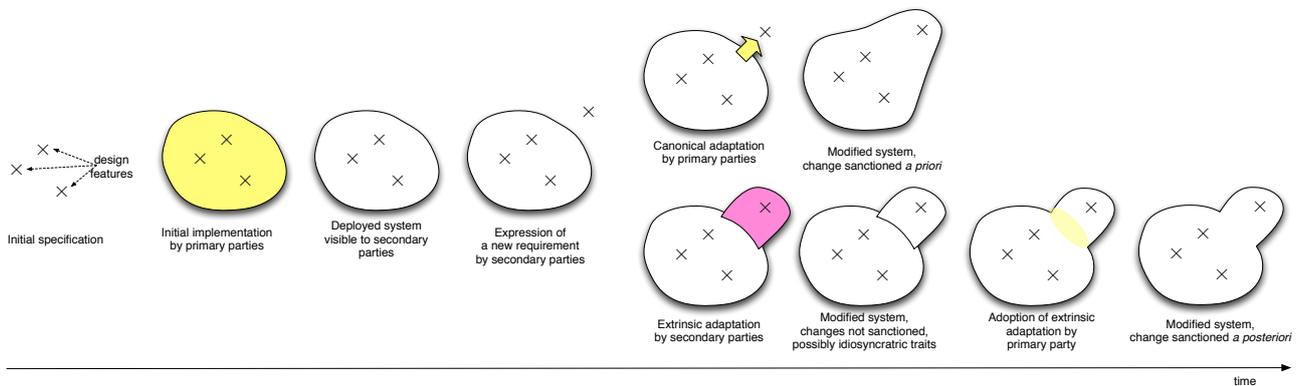


Figure 1: Alternate change strategies to react to new requirements.

### 3 Example scenarios of extrinsic adaptation

The following sub-sections provide concrete examples of extrinsic adaptation and highlight why they are desirable.

#### 3.1 Non-canonical user expectations in a video game

Angry Birds from Rovio Entertainment is a video game running on computers equipped with a touch-sensitive display. From the player's perspective, the primary function of the game is to use birds as projectiles, using finger gestures on the display, to dislodge green pig faces hidden behind movable obstacles. At a high level, this program is thus a function of the finger gestures as input, towards graphical animations and the computation of score points as output.

We consider the system formed by the device and the game program, both being components interacting with each other.

Meanwhile, the free-as-in-beer version of this video game also displays advertisements at the bottom or top of the display while the game is ongoing. The display of advertisements is mostly inconsequential to the players' experience, and usually ignored by them, but owners of slow machines (e.g. an older generation smartphone) can notice that the performance of the game is negatively impacted whenever advertisements are refreshed on the screen, to the point the game cannot be played successfully. An expectation then naturally arises, that these players should be able to play the game on their platforms although this was not tested nor intended by Rovio Entertainment.

The preferred process to overcome this inconvenience is either to acquire a faster machine, or a license for the game that disables advertisements lawfully, or convince Rovio to ensure compatibility with the slower platforms. However, it is easy to conceive of players who are unable and/or unwilling to go these routes before they experience the gameplay.

Meanwhile, users have noticed that the game does not display advertisements if it fails to connect to its advertisement server on the Internet, in which case it can also deliver maximum performance. Once understood, this effect is exploited by users by purposefully disconnecting their device before starting the game. The system components (program & device) are individually not modified; this

is why this change can be considered as extrinsic adaptation.

This example also reveals that a specific extrinsic adaptation may be both desirable to a system's users and relatively undesirable by the primary system providers. However, the example also reveals that the existence of adaptation mechanisms may be a weighed trade-off by the primary providers: while Rovio could in theory cause their program to refuse to run if it cannot reach its advertisement server, this would cause more user frustration and ultimately hurt their bottom line more. Letting some users disable advertisements for the sake of better game play is the lesser of two evils for the company.

### 3.2 Fixing an incomplete specification in a video player

We consider here the example of a video player consumer appliance which can play movies from files stored digitally. Typically, the end users of such video players discover aspects of the running appliance that were not considered initially by the makers. In this example, a shortcoming in the specification of the menu navigation system may render the appliance unable to play videos whose file name contain non-ASCII characters. This observed behavior, and the corresponding user expectation that this behavior should not occur (ie the player should play the video nonetheless), is the symptom of a deviation between the manufacturer's specification and the user-defined specification. The situation is also described by saying that the manufacturer's specification was incomplete.

The usual process for the user to reduce the deviation is to complain to the manufacturer and request a firmware update or a refund to buy a competing product without this defect. Both the user and the manufacturer (and the state regulations) have agreed beforehand explicitly that this process is available to both parties in case of a problem. However, this process yields a time to solution of a few days to a few months, and this delay is usually not controllable by the user. Any change that provides a stop-gap solution in a shorter time frame is thus desirable to the end-user wishing to watch their movie as soon as possible.

Meanwhile, a workaround also exists: for the user to rename the files to using only ASCII characters. Furthermore, using the APIs provided with most video player appliances nowadays, a user-programmer is even able to implement an automated service that performs this file name conversion automatically every time a new file is added to the appliance's storage.

This workaround really tricks the existing components into matching the user's requirement. It can be implemented without involving the primary parties, namely the manufacturer and its design-supply chain. This workaround is thus again an instance of extrinsic adaptation.

This example highlights a key benefit and a key constraint for extrinsic adaptation. The key benefit is the ability for individual parties to obtain a desired behavior more quickly and cheaply than when relying only on the mechanisms and work flows envisioned by the system providers. The key constraint is that extrinsic adaptation is only possible if the system provides extension interfaces to alter its behavior *a posteriori*, in this case the ability to rename files.

### 3.3 Compiler puppeteering for fast back-end prototyping

This author has participated in a project that experimented with different extensions to a processors's instruction set architecture (ISA).

When changing the ISA of a processor, existing programming language compilers cannot be reused as is. To program the new processor, code generation from higher languages than assembly must be implemented as well. However, traditionally code generators have been implemented by considering ISA's as generally stable; the overall process of creating a new "back-end" towards a new ISA is a long-winded process in most compiler frameworks.

For this project it was thus necessary to find a solution that would provide code generation in a faster way than the canonical process offered by existing compiler frameworks. The technical solution explained in [1, App. H] is yet another extrinsic adaptation, which encapsulates the GNU C compiler unchanged into a wrapper program: the wrapper instruments each input source file, and modifies its output assembly code. From the user's perspective, the result looks like a new compiler supporting an extended input language (SL [2]) and a different output ISA. This wrapper is also considerably simpler to modify towards a new target ISA; it was successfully ported to four different target ISAs in less than a man-year worth of work, which would have been more challenging to achieve by performing an intrinsic adaptation of an existing compiler.

In this example, two key features of the compiler tool chain were enabling factors for extrinsic adaptation. The first is that the interface of a compiler, from the perspective of compiler users and building tools, is standardized and ready to accept alternate implementations. The second is that the GNU C compiler itself provides extension mechanisms in its interface, namely run-time parameters to code generation (e.g. `-ffixed-reg`), the C preprocessor which can be used to add new constructs in the language, and the general-purpose `asm` statement which propagates any text from a program to the ISA's assembler without checking its validity.

In other words, the extrinsic adaptation in this case is enabled by both clean component interfaces and built-in mechanisms in the main component to adapt its behavior via special inputs or parameters at run-time.

## 4 Extrinsic vs. invasive adaptation

The definition in section 2 insists on a view where a system is a composite of components with well-defined boundaries, and that extrinsic adaptations are limited to changing the composite without changing the components themselves.

Component boundaries are crucial to evaluate the impact of a change and, by contrast, how much of the rest of the system is left unaffected. The concern here is to provide confidence that the extrinsic adaptation does not remove support for previous requirements (expected features). If the system is viewed as an uncompartimentalized whole without clear component boundaries, or if the boundaries are not respected and components are modified, no confidence could be derived that a modification on a part (or adding a part) has no impact on the behavior of the other parts.

Extrinsic adaptation is thus based on the definition of internal component boundaries, so that a change to the system can be objectively determined to occur either "within" or "outside" a component. If there are no internal boundaries, any change whatsoever has potentially an impact on the entire system; we then call it *invasive*. In general, "extrinsic" vs. "invasive" are extremes on a scale, and two changes can be compared according to whether they are "more

extrinsic” or “less invasive” than the other.

The reason why the distinction between invasive and extrinsic matters is that extrinsic adaptations are subjectively considered more *acceptable* than invasive adaptations in the eye of (human) external observers. *In other words, when a secondary party changes a system and can argue that the change is more extrinsic, it increases its subjective value.* The value can be either monetary, social, moral, ethical or philosophical, or any combination thereof.

A real-world example that highlights the distinction between extrinsic and invasive adaptation can be found by considering a system originally constituted by a horse and a person, and the addition of a new requirement that the person should be able to ride the horse while it is running, without falling. One approach to address the new requirement is to perform a surgical operation to modify the bone structure of both, so that the person’s hip can firmly position itself on the horse’s back. Another solution is to add and use a saddle.

There are multiple ways for an external observer to determine which change is preferable at a subjective level.

One way is to argue that the surgical operation is invasive, because it disrupts biological metabolism and may interfere with the components’ biological integrity in the longer term. In contrast, the addition and use of a saddle respects the biological boundaries and does not interfere with biological integrity. This argument makes the saddle adaptation more acceptable by presenting it as an extrinsic adaptation.

Another way is to argue that the saddle is invasive, because it breaks the direct skin-to-skin contact between human and horse. This separation can be argued to interfere with the overall reactivity of the human-horse system to external stimuli. In comparison, the bone structure operation preserves this physical contact. In this perspective, the relationship between haptic feedback and reactivity is central, and a saddle is more invasive thus less acceptable.

## 5 Limited scope of cost functions

The previous section has highlighted that when component boundaries in a system are unclear, any change to the system by a secondary party may be either considered as extrinsic or invasive depending on subjective criteria.

The distinction is often irrelevant in practice when changes can be associated to a neutral *cost function*. When available, a cost function can both be used to determine whether a change is acceptable, i.e. when the cost fits within a *budget*, and which of two possible changes is preferable, i.e. which has the *lowest cost*. The definition of clear-cut, objective cost functions may thus be seen as a way to bypass the subjectiveness of extrinsic vs. invasive adaptations altogether, and to provide an objective way to evaluate system changes in general.

Alas, the subjectiveness cannot be eradicated entirely.

First, the audience may not agree on which cost functions to use and their relative priority. A typical example is the evaluation of change to a computing system with regard to implementation effort and performance. If the audience does not agree on whether to use effort or performance or both, the cost functions cannot serve to evaluate changes. Then even if the audience agrees to consider both, with the intent to use Pareto efficiency to evaluate changes, still no choice can be made if the relative weight of each cost function is not determined.

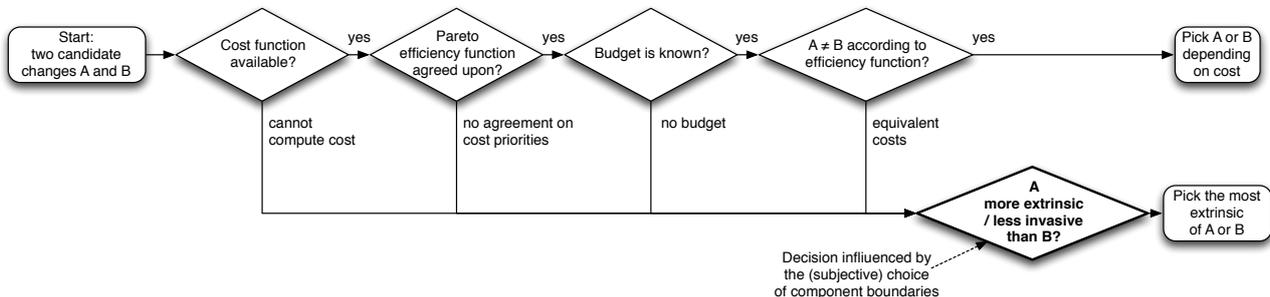


Figure 2: Evaluation process of candidate adaptations to a system.

More fundamentally, cost functions are incomplete. When *budget is not known a priori*, a cost function cannot determine whether a change is acceptable overall. When two candidate changes have *equivalent cost*, cost alone cannot be used to pick one over the other.

We represent this situation in fig. 2: whether a change is invasive or extrinsic is the *ultimate fallback arbitration* when choosing change strategies. This fallback arbitration is also subjectively influenced by the choice of component boundaries, as highlighted previously. Cost functions cannot entirely side-step this subjectiveness.

## 6 Acceptability vs. choice of boundaries

We have highlighted in section 4 that the determination of how extrinsic/invasive a change is requires to first determine component boundaries. If component boundaries are unclear or undefined, evaluation is not possible.

However, any given choice of component boundaries may not be sufficient either. To understand this, consider that component boundaries can be determined in different dimensions of human concern: ownership, origin, vendor, physical frontier, licensing, etc. Therefore, a given concrete change to a system can be more extrinsic from the perspective of one boundary definition, and more invasive from the perspective of another. This observation, together with the observation above that extrinsic adaptations by secondary parties are preferable to invasive adaptations, explains why the duality of extrinsic vs. invasive adaptation creates irreconcilable differences in human communities.

To illustrate this, we can consider the context of software systems, where componentization commonly occurs in two spaces: engineering and marketing. In the engineering space, behavior interfaces are used to enable component-based software design. In the marketing space, ownership and abstract feature boundaries<sup>2</sup> are used to determine the productization of the system.

In this context, there exists an ongoing struggle between proponents of free software and organizations expecting to levy monetary income from software integrations. The struggle occurs as follows. On the one side, free software providers produce software components and systems with the expectation that

<sup>2</sup>Database providers, for example, are known to commonly introduce an artificial boundary between “end users seats” and price licenses per seat, even when the technical implementation only uses one database connection and server instance for multiple end-users.

they can modify both the components and the systems wherever they are reused by third parties. On the other side, organization reuse and integrate this software in larger systems contained in a black box product boundary, either physical (e.g. DRM) or legal (e.g. DMCA). From the free software provider’s perspective, these new boundaries are not relevant to componentization and they feel entitled to adapt the system by adding new software components or modify the integration of existing components. From their perspective, this adaptation is extrinsic. From the product provider’s perspective, adding or modifying the system necessarily violates the provider’s physical or legal boundaries, and is thus invasive. Depending on which side an external observer stands on, the approach that changes such a system by trespassing the physical/legal boundaries and changing the software has either a high or low ethical/moral value.

## 7 Measures of extrinsic adaptability

We assume that the *ability* for secondary parties to perform extrinsic adaptations to a system is generally *desirable*, because it enables secondary parties to satisfy new requirements in a shorter time or lower cost than relying on canonical updates by primary parties.

This ability in turn depends on two factors: that extrinsic adaptations are at all *possible*, and that they can be perceived as *acceptable* according to objective (cost functions) and subjective (invasiveness) criteria. Conversely, systems can oppose *friction* against extrinsic adaptations, either by:

- *technical friction*: by making change difficult to implement;
- *friction against transparency*: by preventing the definition of component boundaries, so that external parties are pushed to consider changes to be generally invasive and thus undesirable.

Note that there is no friction specific to cost functions. Either cost functions are readily available and agreed upon, in which case there is no friction in this aspect; or primary parties make cost difficult to identify or to agree upon, in which case evaluation of changes falls back to the extrinsic/invasive scale subject to system transparency.

In general, a general measure of *extrinsic adaptability* can be taken by evaluating *how little friction* a system opposes to extrinsic adaptations. The following sub-sections detail which measures of friction can be used for this purpose.

### 7.1 Technical friction

There are three general ways that a system’s design can oppose technical friction to extrinsic adaptations:

- *friction against alternate integration*: makes it difficult to combine the existing, unchanged components of the system in a different way, to disable/remove existing components altogether, or to provide them with different input parameters at run-time that could change their behavior;
- *friction against extension*: makes it difficult to add new components next to the existing components in the system;
- *friction against change resilience*: makes it difficult to keep using the adaptation over time.

We do not separate “friction to substitution”, because substitution is really the combination of adding a new component (extension), then disable the existing component and adapt the system to use the new component (alternate integration). Friction to either of these sub-actions is sufficient to oppose substitution.

Note that there exist another form of technical friction against change in general, although this form is not relevant to extrinsic adaptations: friction to component modification. this occurs when a design makes it difficult to open a black box component and change part of its implementation while keeping the rest. This is not a concern for extrinsic adaptation which, by definition, does not involve component modifications and instead relies on changes to the integration between components, assumed to be visible.

The mechanisms by which primary providers create technical friction to extrinsic adaptations in a system include:

- *tight integration*: using complex and multi-layered inter-dependencies between components, which generally makes it difficult to change one part of the system without altering the rest;
- *warranty seals*: refusal to deliver further service or updates after non-canonical changes;
- *component signatures*: cryptographic signing of component implementations, and constructed social disapproval of behaviors from components signed by untrusted sources.

Tight integration is a form of friction against alternate integration. Warranty seals oppose all three forms of friction identified above. Component signatures oppose friction against extension, and thus also against substitution.

## 7.2 Friction against transparency

With limited transparency, any secondary party wishing to develop an adaptation first needs to investigate the system’s inner workings and reconstruct *a posteriori* a model of the interaction between its components, i.e. perform first an act of *reverse engineering* the system back to a design specification.

The mechanisms by which primary providers create friction against transparency and reverse-engineering include:

- *secrecy*: existing knowledge and documentation about the system’s design is hidden away from secondary parties;
- *opaque physical barriers*: using a sealed physical enclosure (bolted enclosure, chip package, etc.) which prevents physical observation;
- *obfuscation*: addition of extra components and interactions which are not necessary to proper system function and just serve to increase the effort necessary for reverse-engineering;
- *encryption*: encryption of interactions between components, which hides the interaction protocols and prevents reverse-engineering component interfaces;
- *alienation*: using an unusual overall design for the system when alternate, better-known approaches exist.

### 7.3 Relative impact of friction types

Friction against transparency is fundamentally less strong than technical friction. Indeed, as soon as one sufficiently motivated secondary party overcomes obstacles to transparency, the accrued knowledge from reverse-engineering can be gathered, published and made accessible for multiple subsequent adaptations. The costs incurred by friction against transparency can thus be amortized over time.

In contrast, technical friction induces extra implementation costs in *each* extrinsic adaptation, and thus cannot be amortized. When found in a system, friction against transparency can be perceived more as a mere temporary inconvenience, whereas technical friction can be perceived as a serious obstacle worth complaining about.

## 8 Extrinsic adaptability in computing systems

Software systems are traditionally well componentized. With the popularization of open source software in the late 1990's, and the large democratization of software engineering that followed, the friction against extrinsic adaptation of software has been generally reduced. Since then, despite the occasional transparency obstacle in proprietary, closed source components, large software systems are largely extrinsically adaptable.

The picture is not so clear when the boundary of a computing system is extended to include hardware components, i.e. the hardware platform.

On the one hand, the industrial world where computing hardware is produced is culturally largely opposed to transparency, and the various mechanisms identified in section 7.2 are commonly used. And in the occasional case where secrecy, obfuscation, encryption and alienation are not expressly sought by system providers, miniaturization and especially chip packages create opaque physical barriers that are difficult to overcome. Even though friction to transparency can be considered mostly an inconvenience (cf. section 7.3), the associated overheads to extrinsic adaptation exist in every hardware platform.

On the other hand, there exist large opportunities to reduce technical friction, although they are currently not commonly considered.

To begin with, consider that large efforts were made in the last three decades of the 20th century to build modular hardware platforms, e.g. with interchangeable memory, processor and interconnect components. This systematic reduction of technical friction against extrinsic adaptation was justified by a strong demand for adaptable hardware by the user base, which itself was a side-effect of the personal computing revolution of the '70s and early '80s.

Since then, as the customer base for hardware products has extended beyond the community of hobbyists, the demand for adaptable hardware has *relatively* dwindled<sup>3</sup>. Simultaneously, tight sales margins favor tight integration, often in the form of specialized hardware and systems-on-chip. And for all systems with multimedia output, the political atmosphere has facilitated the pervasive use of component signatures. All these factors have created tremendous technical friction against extrinsic adaptation.

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<sup>3</sup>We postulate that in absolute economic value, the demand for adaptable systems has even increased, albeit less fast than the overall demand for computing systems.

But the current situation does not invalidate the benefits and desirability of extrinsically adaptable systems. A known way to design for extrinsic adaptation is to exercise hardware modularity and standard hardware interfaces. More adaptable systems would reduce vendor lock-in, increase reusability and thus eventually reduce waste and evolution costs. Moreover, renewed interest and demand for extrinsic adaptability is only a slight cultural shift away: a more open political mindset, and a manufacturing overhead eventually compensated by the aforementioned longer-term benefits.

We can thus argue for the existence of an *ethical imperative* for hardware architects and platform providers to stimulate extrinsic adaptivity, as a particular instance of the more general imperative to favor long-term priorities over short-term gains.

## 9 Conclusion

We have distilled the concept of *extrinsic adaptation* to a system of components, a generalization which encompasses the popular concepts of “workaround” or “hack” when talking about changes to an existing system by secondary parties.

We have also highlighted that system changes by secondary parties fall on a subjective gradient of acceptability, with extrinsic adaptations on one side which confidently preserve existing system features, and invasive modifications on the other side which are perceived to be disruptive to existing system features. Where a change is positioned on this gradient is dependent on how an external observer perceives component boundaries within the changed system. We have also argued that the existence of objective cost functions can alleviate but not fully eliminate this subjectiveness.

The general benefits of extrinsic adaptations have then led us to define general metrics to evaluate how much systems are amenable to extrinsic adaptation, i.e. measure their extrinsic adaptability. We do this by considering the opposite force, i.e. friction against adaptability, and identifying the mechanisms currently in use by system providers to oppose friction.

We have then applied the proposed concepts to the case of computing systems, and formulated a general ethical imperative to promote extrinsic adaptability in hardware platforms.

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