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# Reply to Dew's (2007) commentary: "Pre-adaptation, exaptation and technology speciation: a comment on Cattani (2006)"

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This article responds to the critique by Nicholas Dew (2007) on an earlier article by Cattani (2006) which suggested that Cattani's use of the term "pre-adaptation" should be replaced by an alternative term "exaptation." The article responds to that suggestion and attempts to redirect discussion toward the evolutionary significance of pre-adaptation within the context of technology, a task central to any evolutionary theory of technological change.

In a recent commentary of my paper "technological pre-adaptation, speciation, and emergence of new technologies: how Corning invented and developed fiber optics" published in *Industrial and Corporate Change* (2006), Nicholas Dew criticizes the use of *pre-adaptation* as a confusing concept and offers an alternative term—*exaptation*—that in his view better describes the process I refer to in my article. I would like to first thank Dew for his overall laudatory evaluation of my study. It is always very flattering to see that someone has taken the time to read your work very carefully, even when it may inspire a critical, but constructive reaction. I would also like to thank Dew for "forcing" me to think more deeply through the implications of using the term *pre-adaptation* as opposed to *exaptation*, especially in the context of technology (for an interesting discussion of this particular point see Dew *et al.*, 2004).

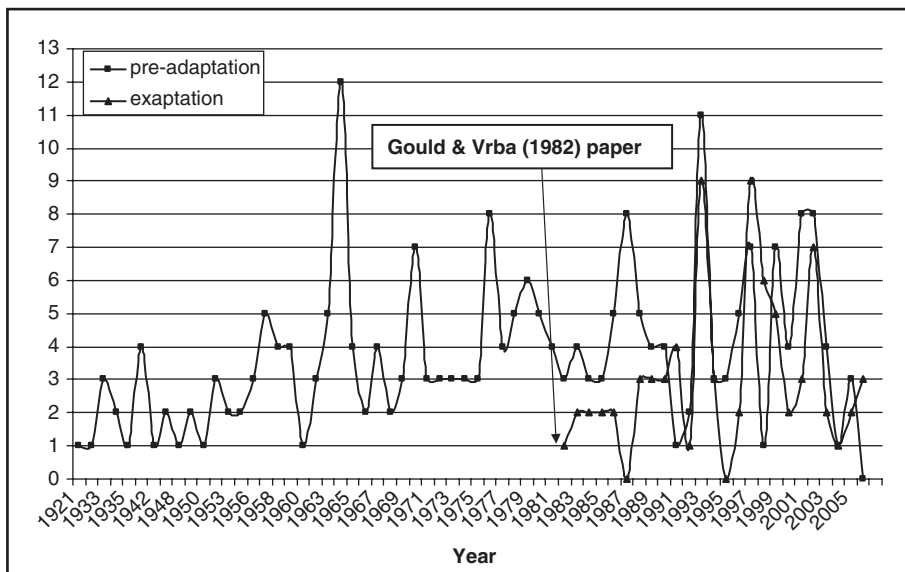
My objective here is to reply to Dew's penetrating remarks by arguing that exaptation faces many of the same issues that the term pre-adaptation has long been struggling with. In this reply, I want to address the main concerns raised by Dew and in particular counter his claims that (i) the term pre-adaptation has faded from the discipline of biology, (ii) foresightful adaptation might be involved in the notion of pre-adaptation, and (iii) exaptation is a less confusing term to explain the phenomenon I investigate in my research. In order to avoid the risk of confining the discussion to what might otherwise be perceived as terminological "quibbles,"

I will also elaborate on the implications of using pre-adaptation within the context of technology. Besides clarifying important differences between biological and technological evolution, I argue that it is critical to understand the meaning and role of pre-adaptation to discriminate conceptually between the case in which plainly foresighted developments can be observed and the case in which foresight is not involved.

## 1. Has pre-adaptation been selected out?

Dew (2007: 156) claims that over the years “the discipline (of biology) has gradually selected-out the term pre-adaptation.” Received evidence however offers a rather different picture: the term pre-adaptation has not faded away at all and it is still very much in use. Figure 1 reports the number of articles published in some leading biological journals—such as *Science*, *Ecology*, *Biological Bulletin*, *Bioscience*, and *Evolution*—where the terms pre-adaptation and exaptation are alternatively adopted. The term exaptation appears for the first time in 1982 when the article by Gould and Vrba (1982) was published in *Paleobiology*. The pattern shown in the figure is basically the same even if one includes articles from other journals, e.g., *Proceedings: Biological Sciences*, *Trends in Ecology & Evolution*, and so on.

It is worth noting that there is no evidence suggesting that exaptation has taken over and displaced pre-adaptation after 1982. As the number of papers using one term or the other clearly indicates, there is no ground for Dew’s (2007: 156) claim



**Figure 1** Number of papers using “pre-adaptation” versus “exaptation”.

that over the years “the discipline (of biology) has gradually selected-out the term pre-adaptation.” This conclusion is further corroborated by the fact that very influential textbooks on evolutionary biology—e.g., *Evolution* by Mark Ridley and *Evolutionary Biology* by Douglass Futuyma (1998)—offer a rather different characterization of the debate and/or take on a more neutral position on the topic.

While this evidence cannot be regarded as conclusive, it nevertheless indicates that exaptation has not yet taken over pre-adaptation—which is clearly contrary to Dew’s claim. This result is hardly puzzling because, as I will explain in greater details in the next two sections, neither pre-adaptation does imply design or foresightful adaptations nor is exaptation clearly a better term.

## 2. Does pre-adaptation involve “foresightful adaptation”?

The second issue raised by Dew has to do with the possibility that pre-adaptation might bring to the fore the spectrum of foresightful adaptation. Since natural selection involves no foresight or teleology, he argues that:

At face value, prefixing “pre” to adaptation suggests that one is referring to an adaptive process taking place before . . . that is, that the adaptive process must have occurred before the fitness-value of the feature in question was in fact apparent. This suggests that some kind of foresightful adaptation is involved in pre-adaptation. But this notion contradicts one of the basic principles of evolutionary theory, that the process of natural selection involves no foresight. It also contradicts the intended meaning advocates want to give to pre-adaptation, as I understand it (pp. 155–156).

Dew’s interpretation of the meaning of pre-adaptation is rather puzzling because the lack of foresight or teleology in biological evolution is no longer a matter of debate (among the others, see a recent paper by Sniegowski and Murphy, 2006). This point is clearly stated in this excerpt by Ridley (1999: 346–347), also reported in both of my papers:

Pre-adaptation does *not* [emphasis added] imply any futuristic or anticipatory faculty in evolution [. . .] Sometimes, by chance, an organ that works well in one function turns out to work well in another function after relatively little adjustment.

As a result, prefixing “pre” to adaptation simply means that the adaptive process occurred “before” as my analysis of the emergence and evolution of fiber optics clearly shows. Any concern about the spectrum of “foresightful adaptation” lurking behind the idea of pre-adaptation is tantamount to worrying about a “non-issue”. Thus, I hardly see any disagreement between my position and that of Dew on this point.

Intentional factors are on the contrary incorporated into an evolutionary theory of technological change. A key difference between biology and technology is that foresightful evolution can actually occur in the context of technology. As Ziman (2000: 6) pointed out, this difference stems from the observation that "... technological change is driven by variation and selection – but these are clearly not 'blind' or 'natural.' This work is being done largely by conscious human effort, without apparently needing guidance from any 'hidden hand,' whether of Nature, the market, or God." A more substantive question therefore has to do with when new technological developments can be viewed as the result of (some degree of) foresight.

In addressing this question it is important to qualify what "this work is being done largely by conscious human effort" actually means. Of course, the assumption that "... the origins, direction, and influence of technological change are under *complete* [emphasis not in the original] human control" (Basalla, 1988: 211; see also Nelson and Winter, 1982) clashes with received evidence and is at odds with the evolutionary perspective. As people do not see the future very well, we should restrain from assuming that they can see the future when we try to explain their behavior (Murmann *et al.*, 2003). Especially in the context of R&D management where decisions are typically made in a highly unfamiliar territory a lot of the "key things that happen in the course of an R&D project are happening for the first time ever. The *ex ante* uncertainty about such things does not relate just to *whether they will happen*, it relates to *what they are* – because they haven't been seen before" (Winter, 2005: 526).

Despite the evolutionary perspective's skepticism about the role of foresight, there are plainly foresighted technological developments that are "clearly" seen. Moore's Law in the semiconductor industry provides an interesting illustration. The law describes what has been an important trend in the history of computer hardware for more than half a century: that the number of transistors that can be inexpensively placed on an integrated circuit is increasing exponentially, doubling approximately every two years. The observation was first made by Intel co-founder Gordon E. Moore in a paper published in 1965 in *Electronics*. Although many working "in the semiconductor industry back then had noticed the same trend, he was the first to publish the idea" (BBC NEWS, April 18, 2005). This general trend was anticipated not merely out of a lucky guess but on the basis of a deep understanding of chip design, solid-state physics, and materials' properties.

The new drug development method in biotech is another interesting example. Prior to the late 1970s, pharmaceutical research was conducted largely through a process of so-called "random" search. From the late 1970s on, firms began to respond to the acceleration in the growth of publicly available biological knowledge by adopting a new search process called "science-driven" drug discovery (Cockburn *et al.*, 2000). The adoption of this new method followed the paradigm shift triggered by the advent of bioinformatics which, unlike traditional biology, is "based upon data collection and storage and the mining (retrieval and integration) of the

databases in order to generate knowledge” (Bull *et al.*, 2000: 577).<sup>1</sup> With increased emphasis placed on the introduction of blockbuster drugs, firms adopting the new techniques have become significantly more productive in developing new drugs (e.g., Henderson and Cockburn, 1994; Cockburn *et al.*, 2000). This is largely explained by the fact that the progress of theoretical knowledge “towards more fundamental explanations allows to identify a certain number of search trajectories that will not lead to the production of new drugs in the treatment of given pathologies” (Orsenigo *et al.*, 1998: 154).

Pre-adaptation reminds us that many technologies cannot be clearly seen as the result of foresight. The same holds true for current applications of those technologies that do not always coincide with the use that was originally envisioned for them. Burgelman’s (1994) account of Intel’s invention of the microprocessor is a case in point. Intel’s initial success stemmed from its core DRAM business, but early on its technological competence generated two important innovations: EPROMs and microprocessors. These innovations “were *unplanned* [emphasis not in the original] new technologies with major commercial potential” (Burgelman, 1994: 37).<sup>2</sup> Faced with the pressures of a dwindling market performance in the memory business, Intel underwent a strategic renewal which entailed a radical shift of its product portfolio (from DRAMs to microprocessors) to reflect more closely the new strategic priorities, and culminated with a change in leadership that led Andy Grove, who viewed the microprocessor to be the basis for Intel’s future growth and profitability, to become the new CEO of the company.

The Intel case is insightful because it shows how technologies that managers often describe as “created” through deliberate efforts are not the result of foresightful anticipation. This attribution bias inevitably informs accounts of new technological developments whereby actors—especially those involved in those developments—retrospectively tend to stress the role of intentionality over alternative explanations that place greater emphasis on random chance or serendipity. Incidentally, it is worth noting that this issue lies at the core of a longstanding debate on the role of luck or accidental discoveries in science (for a very comprehensive discussion see Merton and Barber, 2004). Scholars interested in technological evolution (and the

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<sup>1</sup>“In traditional biology the search strategy is based upon specimen collection, system observation, and laboratory experimentation in order to organize knowledge in a systematic way and to formulate concepts. Outcomes of this approach might be illustrated by the serendipitous discovery of antibiosis or the later targeted development of enzyme inhibitor screens” (Bull *et al.*, 2000: 577).

<sup>2</sup>“EPROM was invented by Dov Frohman, who was trying to understand and remedy a strange phenomenon that was causing reliability problems with Intel’s MOS process technology. Even though there were no immediate market applications, CEO Gordon Moore decided to support the new technology. Microprocessors came about because Basicom, a Japanese calculator company, contacted Intel for the development of a new chip set. Basicom had envisioned a set of around 15 chips designed to perform advanced calculator functions” (Burgelman, 1994: 37).

evolutionary forces behind it) should therefore use extreme care to establish to what extent *ex post* recollections are likely to over-emphasize the actual role of foresight in new technological developments.<sup>3</sup>

Firms can also intentionally foster variety itself by creating new technological knowledge not because they have already identified a useful application for it, but because there is a higher level belief that this knowledge might prove useful in the future. Since the range of possible applications for a firm's technological knowledge base is typically wider than its current applications, firms can capitalize on previous technological investments by leveraging that knowledge into novel applications as they come along (e.g., Garud and Nayyar, 1994). In their study on IDEO's unique way of organizing for innovation, for instance, Hargadon and Sutton (1997) showed how the process of storing, retaining, and retrieving knowledge was critical in developing new technologies consistently over time. This process, including the underlying routines and practices (e.g., having regular brainstorming sessions, using prototypes or product parts, keeping written records of previous projects, etc.), enhanced the likelihood of making connections between otherwise unconnected bodies of non-redundant knowledge. Technical problems tend to change continuously, but the same body of knowledge can remain valuable as individuals "recognize similarities between old solutions and new problems" (Hargadon and Sutton, 1997: 732).

The previous example is consistent with my use of the term pre-adaptation in the context of technology. Prior research has investigated how firms can deliberately organize or prepare for serendipitous discoveries (Garud *et al.*, 1997). Yet this does not imply that new technological developments and/or their applications are clearly foreseen. Rather, it means that firms' ability to capitalize on technological opportunities that arise from their past R&D can be enhanced significantly via organizational design and *ad hoc* routines and practices. Foresight in this case is embedded in the process by which new technologies are created, more precisely the way the process is actually organized and managed, not the final outcome (i.e., the particular technology being developed), which very often was not initially anticipated.

### 3. Is exaptation a better term?

Dew finally argues that exaptation is a less confusing term to explain the phenomenon I investigate in my research. This claim however is quite inaccurate.

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<sup>3</sup>In my study on Corning's invention of fiber optics technology, I tried to deal with this concern by relying on internal corporate documents that date back to the period when fiber optics was first identified as a potentially valuable investment opportunity and the decision to invest in it was subsequently made. The use of such documents reduces significantly the risk of retrospective sense-making, namely imposing meaning on outcomes after the facts.

As we shall see, since exaptation encompasses both adaptations and non-adaptations, it is questionable whether it is really a less confusing term. Before discussing the merit of using exaptation as opposed to pre-adaptation, however, it is important to analyze briefly its theoretical antecedents in biology.

If one looks at historical changes in the evolution of an adaptation, it is possible that at every stage an organ served the same function (the evolution of the eye is a good example because in all stages it probably performed visual functions), or the earlier stages could possibly have performed different functions than the later ones. The classical Darwinian term for the second possibility is pre-adaptation, whereby the earlier stage is described as a pre-adaptation for the later stage. The idea that the function of a trait might shift during its evolutionary history originated with Charles Darwin (1859, Ch. 6) who gave “change” of function and “improvement” of function equal emphasis in his discussion of the origin of complex adaptations, as have most major evolutionary biologists since then.

Despite the concern that the term pre-adaptation might suggest forethought (see my previous discussion), following Ridley (1999: 347) in both my papers (Cattani, 2005, 2006) pre-adaptation is applied only “when a large change in function is accomplished with little change in structure.” This notion of pre-adaptation is consistent with Bock (1959: 209)'s original discussion, particularly when he says that “[. . .] the pre-adapted level is a threshold at which there is a functional shift, not a morphological shift. Because this shift has great functional and evolutionary significance, it may appear that it also involves a large morphological change; however, this “morphological change” is more apparent than real.” The evolution of tetra pod limbs provides a nice illustration of this shift in function without any major morphological change because a structure which was effective at locomotion in water was also good at locomotion over land with relatively few changes.<sup>4</sup> Pre-adaptations show that evolution is not purpose-driven; there is no intelligent driving force behind the process, and therefore no end goal. In this sense, natural selection is a tinkerer, not a designer.

Calling into question the idea that current traits or structures have adaptive origins, Gould and Vrba (1982) suggested the use of exaptation as a better term than pre-adaptation to describe the case where a trait or structure is a non-adaptation.<sup>5</sup>

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<sup>4</sup>Likewise, the red panda's wrist bone was already extant in its ancestors and it happened to be useful in grasping bamboo. After thousands of years of selection, the bone has expanded and is increasingly more helpful in the population.

<sup>5</sup>Gould and Vrba (1982: 6) go on to say that “[T]he set of adaptations existing at any one time consists of two partially overlapping subsets: the subset of adaptations and the subset of exaptations”. The general static phenomenon of being fit should be called aptation, not adaptation. I refer the reader to the original paper for a discussion of this additional distinction, which is not critical for the argument made here.

**Table 1** A taxonomy of fitness (Gould and Vrba, 1982: 5)

Process	Character		Usage
Natural selection shapes the character for a current use—adaptation	Adaptation	} Aptation	Function
A character, previously shaped by natural selection for a particular function (an adaptation), is coopted for a new use—cooptation	} Exaptation		} Effect
A character whose origin cannot be ascribed to the direct action of natural selection (a nonadaptation), is coopted for a current use—cooptation			

More specifically, as indicated in Table 1 (which reproduces Gould and Vrba's original table), an exaptation is observed when:

1. A character, previously shaped by natural selection for a particular function (an adaptation), is co-opted for a new use—cooptation.
2. A character whose origin cannot be ascribed to the direct action of natural selection (a non-aptation), is co-opted for a current use—cooptation.

A potential problem with the notion of exaptation is that “it includes not only pre-adaptations, but also the theoretical possibility of initially neutral character that later evolves a positive function” (Ridley, 1999: 348). These two categories in fact have different implications for the role of adaptation. Thus, while I acknowledge that “features of organisms—or technologies—can have non-adaptive origins, that is, they might evolve for one reason, or for no apparent reason, and then later be co-opted for a new role . . .” (Dew, 2007: 157), I disagree with Dew's characterization of my study, in particular when he maintains that:

It is this notion that new technologies might emerge out of non-adaptive origins that appears to be Cattani's point about Corning's fiber optics: a case where “firms accumulate knowledge without anticipating its subsequent applications” (Cattani, 2006: 290). The point seems to be that R&D labs often seem to accumulate a lot of “stuff” laying around: R&D rubbish.

This interpretation of the process described in my paper is largely inaccurate. Figure 1 in Cattani (2005: 307) reports some of the key technological antecedents

(i.e., technologies developed for other, more or less related, technological fields or applications) that contributed to defining Corning's technological pre-adaptation for fiber optics. Much of this prior accumulated (technological) knowledge was actually adaptation for the particular (though different) uses for which it was originally created. This knowledge however also proved valuable with respect to the new (though unanticipated) application, i.e., fiber optics for long-distance telecommunications. That "stuff" in other words was not just "R&D rubbish" as my analysis of the process through which Corning pioneered the first low-loss optical glass fiber clearly demonstrates.

The confusion in Drew's interpretation is to ascribe mainly to the fact that exaptation encompasses both adaptations and non-adaptations—i.e., the case of a character previously shaped by natural selection for a particular function (an adaptation) that is co-opted for a new use and the case of a character whose origin cannot be ascribed to that direct action of natural selection (a non-adaptation) that is co-opted for a current use, respectively (Table 1). The first case (adaptations) corresponds to actual pre-adaptations and is the phenomenon described in my papers. Of course, I do not rule out the possibility that prior R&D might produce "rubbish" (i.e., non-adaptations), as Dew *et al.* (2004) show in their paper. I nevertheless refrain from making any such distinction because it is very difficult to discriminate precisely between the two cases—even though they are conceptually distinct. Yet using a term (exaptation) that encompasses both adaptations and non-adaptations is confusing because one is left with the challenging task of clarifying when one or the other case actually recurs.

The previous discussion also points to a more general issue facing history-laden definitions of adaptation that neither the use of the term pre-adaptation nor the use of the term exaptation can safely claim to resolve. As Reeve and Sherman (1993: 4) noted:

[...] whether a trait is labeled an adaptation or an exaptation depends arbitrarily on the point in history at which we examine the trait's function. In all the sequences the present trait may owe its existence to natural selection, but it would be recognized as an exaptation in Gould and Vrba's historical scheme only in some cases, depending on our knowledge of its functions at different times in geological history. Functions at many times may be unknowable. For example, if multiple function-transitions occur between speciation events, no phylogenetic "memories" of the multiple functions will be preserved in extant species.

As a scholar interested in the evolution of technology, I am inclined to read this quote not as a threat against historical analysis but instead as an invitation to use extreme care in identifying the very moment "cooption"—i.e., a shift in function of

a trait or structure—actually occurred. Depending on exactly when this transition is situated in time one might in fact consider the “cooptation of a trait or structure” as an instance of exaptation with adaptive (the same as pre-adaptation) or non-adaptive origins, respectively.

## Conclusions

The term exaptation is not immune to some of the conceptual shortcomings that are typically attributed to the term pre-adaptation. Although it is important to recognize the evolutionary role of non-adaptations to properly understand the genesis of existing traits or structures (in our case, technologies), it is unclear how the introduction of a new term that includes both adaptations and non-adaptations may help solve the exaptation/pre-adaptation conundrum once and for all. The main reason for the confusion that surrounds the term exaptation is that it subsumes two distinct evolutionary phenomena, i.e., adaptations (pre-adaptations) and non-adaptations. A viable approach to remove this confusion therefore is to focus on the substantive differences between these two cases rather than simply proposing new terminology.

Even if one feels uncomfortable about using the term pre-adaptation, the previous discussion casts some doubt on the presumed advantages of substituting exaptation for pre-adaptation. As Dennett (1995: 281) pointed out:

[...] every adaptation is one sort of exaptation or the other—this is trivial, since no function is eternal; if you go back far enough, you will find that every adaptation has developed out of predecessor structures each of which either had some other use or no use at all. The only phenomena that the Gould’s exaptation revolution would rule out are the phenomena that orthodox adaptationists “quickly” disavowed in any case: planned-for pre-adaptations.

In conclusion, after recognizing similarities but also important differences between biological and technological evolution, a more fruitful discussion on the evolutionary significance of pre-adaptation within the context of technology should be aimed at establishing the meaning and role of foresight in new technological developments. In this sense, I hope my reply will contribute to redirecting the discussion towards this more substantive issue, which is central to any evolutionary theory of technological change.

## Acknowledgements

I would like to thank Sidney G. Winter (Wharton) for his valuable precious insight. All errors remain my own responsibility.

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