A functional abc for biotechnology and the dissemination of its progeny

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1. Introduction

Despite its realised and envisaged benefits, and despite its similarities to more traditional forms of biotechnology, there is an on-going and general worry about the dissemination of genetically modified organisms (GMOs). Already right in the beginning of the 1970s, when genetic engineering experiments with micro-organisms started, there was a reaction among molecular biologists endorsing that manipulated micro-organisms should be contained in the laboratory and never be released into the environment. Since then, guidelines and rules were set up to guide the development of genetic engineering, yet calls for containment continued to be made. Nowadays some medical products, such as insulin and human growth hormone, and some industrial enzymes, such as chymosin, the enzyme for producing cheese, are produced with the help of genetically manipulated micro-organisms, and these organisms are not released into the environment. Yet recombinant plants for commercial horticulture grow are increasingly released, leading especially in Europe to public concerns about the unforeseeable consequences of the dissemination of these GMOs. The controversies around GMOs raise the question of the particularity of genetic engineering. Genetic engineering can on an abstract level be considered as just another form of biotechnology, similar to the domestication and breeding of organisms by humans. Hence, what makes genetic engineering so special that its development and products lead to on-going attempts to check these developments and products?

In this paper we take up this question. We develop a general and abstract analysis of biotechnology in which genetic engineering can be accommodated as a special case. With this analysis one can articulate particular threats of the dissemination of GMOs that typically do not arise for more traditional forms of biotechnology.

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And with this analysis one can articulate circumstances in which the dissemination of GMOs is less threatening.

In sections 2 to 4 we present our general analysis of biotechnology building on work by Dan Sperber (2007). By this analysis biotechnology is characterised in primarily functional terms as special cases of interactions between different organisms, namely as interactions in which humans modify other organisms for letting these other organisms perform technical functions by, for instance, their biological functions. We identify in section 5 three general routes by which this interaction can proceed, routes that hold equally for traditional forms of biotechnology as for state-of-the-art genetic engineering. By two of these routes genetically changed organisms are created and reproduced.

In section 6 we describe the failure modes for the controlling of the dissemination of the modified organisms for each of the three biotechnological routes. Our functional perspective on biotechnology allows us in a fairly natural way to articulate these failure modes. In general the functions of items are the capacities for which those items are reproduced: human actions reproduce technical artefacts for their technical functions and natural evolutionary forces favour the reproduction of organisms for their biological functions. Hence, if an organism is modified to have a capacity that can serve a technical function—which typically is the aim in biotechnology—then human action may lead to the dissemination of similar organisms with that capacity. And if the capacity for which the organism is modified becomes a biological function of that organism, then natural evolutionary forces favour this dissemination as well. The functions of biotechnologically modified organisms thus single out those capacities for which the organisms are reproduced, and provide, moreover, information about the mechanisms by which organisms with those capacities are reproducing.

In section 7 we focus on what makes genetic engineering particular within biotechnology. Building now on the work by Alfred Nordmann (2008), we argue that the microscopic size of GMOs leads to a practical epistemic difference between the dissemination of GMOs and the dissemination of more traditional biotechnologically modified organisms: instances of each type of organism can lead as exotics to substantial threats to environments and to ourselves, but in contrast to the macroscopically sized products of traditional biotechnology, the dissemination of GMOs cannot be recognised as the dissemination of modified organisms. GMOs can thus not be controlled by the means we have developed for controlling modified organisms of traditional biotechnology, making that possible threats of GMOs take the uncanny character of natural disasters as those induced by undetectable germs, viruses or bacteria.

We consider strategies towards preventing dissemination and uncanniness in section 8 and end with conclusions in section 9. The upshot of our analysis is that a functional perspective can provide a general framework for understanding biotechnology in its different realisations, and can be used for articulating and addressing a number of on-going concerns about genetic engineering. We start by presenting this general functional framework.

2. A functional abc for biotechnology

Our analysis of biotechnology is building on a functional framework that Dan Sperber (2007) developed with the aim of analysing the relationships between humans and other organisms. Sperber considers organisms such as leeches, domesticated animals, crops and seedless fruits, which can have three types of functions simultaneously: artifactual functions, biological functions and cultural functions. His framework, and the definitions of these three abc types of function have however a much broader scope than human interference with other organisms; its strength is that it allows to describe interactions between plants, animals and material objects generally.

Sperber’s general notion of function, which has biological and cultural functions as special cases, is the notion of teleofunction, and is inspired by the work of Ruth Garrett Millikan (1984, 1993). Sperber defines teleofunctions in the following terms: “an effect of type F is a teleofunction of items of type A just in case the fact that A items have produced F effects helps explain the fact that A items propagate, i.e. keep being re-produced.” (2007, p. 128; emphasis in original) Phenotypical features of organisms are the items that can have biological teleofunctions, and Sperber takes phenotypical features in a wide sense by adopting Dawkins’s notion of the extended phenotype. Phenotypical features include “bodily features but also behavioral features such as nest-building behavior in birds and outcomes of these behaviors such as the nests themselves” (2007, p. 128). Items that can have cultural teleofunctions are what Sperber calls mental representations and public productions: “Mental representations are constructed within agents by mental processes. By ‘public productions’, I mean both behaviors (e.g. speech) and traces of behavior (e.g. writings) that can be perceived and therefore serve as input to the mental processes of other agents.” (2007, p. 128) Sperber’s example of cultural teleofunctions is the attractiveness of suntans to humans (that is, of human mental representations of suntans and of the actual suntans being the human public reproductions of mental representations suntans). Yet cultural teleofunctions are not limited to the human sphere only since Sperber also describes the picking of blue tits, a kind of bird known for their ability to tear down and open the foil tops of milk bottles and drink the top layer of milk, as behaviour that is culturally reproduced for its rewarding effects (2007, p. 127). Sperber defines the notion of artifactual function separate from his general notion of teleofunctions: the artifactual functions of an item are the intended effects that explain why the item is being produced: Sperber’s example is now a tree leaf that is folded by someone for the purpose of retrieving a ring fallen between the crack of two floorboards. This folded leaf has retrieving the ring as its artifactual function but not necessarily as a cultural teleofunction since the folded leaf need not be an instance of a type that is propagating (2007, p. 129). Yet Sperber notes that artifactual functions may quickly become cultural teleofunctions once artefacts are being reproduced for their artifactual functions.

The three types of functions define in Sperber’s framework also types of items: items with artifactual functions are taken as artefacts, items with biological teleofunctions as biological items, and objects with cultural teleofunctions as cultural items. Artefacts that have their original artifactual functions also as cultural telefunctions, are called cultural artefacts by Sperber. Biological cultural artefacts are similarly items that have a specific effect as an artifactual function, a specific effect as a biological telefunction and a specific effect as a cultural telefunction.

When humans are involved in the (re)production of what now can be called biological artefacts or biological cultural artefacts, one has entered the domain of biotechnology that we wish to analyse in this paper. Before doing so, we define the three types of functions in somewhat more detail. With our definitions we import elements of recent analyses and discussions of biological and technical functions (e.g., Krohs & Kroe, 2009; Houkes & Vermaas, 2010), and depart at points from the ones given by Sperber. We speak, for instance, about biological and cultural functions without using the prefix “teleo” and we add, following Neander (1991), that biological functions of items of organisms are required to contribute also to the reproduction of those organisms; by Sperber’s definition an item’s biological telefunction need merely to contribute to the reproduction of that item, allowing in principle that this telefunction has neutral or even detrimental consequences to the long-term survival of the organisms having the item. Our
analysis of biotechnology can be seen as a particular extension of Sperber’s (2007).

3. Artifactual, biological and cultural functions

Let $a_x$-function be shorthand notation for an artifactual function for species $S$, let $b_y$-function be shorthand for a biological function for species $S$, and let $c_z$-function be shorthand for a cultural function for species $S$. We define these functions as follows:

Artifactual functions for species $S$:
An item $x$ has for an agent $y$ of species $S$ a capacity $\phi$ as an $a_x$-function when $x$ is intentionally selected, modified or made by $y$ for having $\phi$ with the objective that $x$ can be used for this capacity $\phi$ to realise a specific goal.

For instance, let $x$ be a chair, and $S$ be *Homo sapiens sapiens*. This chair has the capacity to support back and bottoms of specimen $\phi$ of $S$-artifactual function— as an $a_x$-function, more shorty— because it was made for supporting back and bottoms by a human being with the objective that it be used by (other) human beings to sit on. Another example could be the shaped wire used and produced by New Caledonia crows (*Corvus moneduloides*) for picking up things that are out of their reach (Hunt & Gray, 2003). Assuming that New Caledonia crows can act intentionally, the capacity of the shaped wire to lift things is its crow-artifactual function— it's $a_x$-function, more shortly.

Items that have artifactual functions are paradigmatically inanimate items. Yet, one of the points Sperber is making is that also biological organisms or items of those organisms can have artifactual functions. Canaries (*Serinus canaria*), for instance, can have for humans the $a_x$-function of detecting mine gas.

Biological functions for species $S$:
An item $x$ has for an organism $z$ of species $S$ a capacity $\phi$ as a $b_y$-function when items of $x$’s type contributed to the inclusive fitness of $z$’s ancestors by doing $\phi$ and when this doing $\phi$ of the items of $x$’s type caused the genotype, of which $x$ is the phenotypic expression, to be selected by natural selection.

The pumping capacity of the hearts of organisms of species $S$ is the most common example of a $b_y$-function. Yet, adopting the notion of the extended phenotype, also items and organisms that are not specimens of $S$ can have biological functions for organisms of that species $S$. The capacity of spider webs to capture insects has for the spiders the $b_y$-function to catch prey. Nectar collecting hummingbirds that co-evolved with long tubular ornhithophilous flowers of plants of some species $P$, have for those plants the $b_y$-function of disseminating their pollen.

Cultural functions for species $S$:
An item $x$ has for an organism $z$ of species $S$ a capacity $\phi$ as a $c_z$-function when items of $x$’s type were employed by other organisms of species $S$ for $\phi$-ing for realising a specific goal, and when this employment of items of $x$’s type for $\phi$-ing caused via social learning that the organism $z$ employs the item $x$ for $\phi$-ing for realising that goal.

For instance, the picking behaviour of Blue tits (*Cyanistes caeruleus*) has for those tits the $c_z$-function of making milk available for consumption, among other things, since Blue tits exhibit this behaviour and since Blue tits copy this behaviour from one another. Wood has the human cultural $c_y$-function of making fire, among other things, since humans have used wood to make fires and other humans have adopted this use via social learning. And canaries have their capacity of detecting mine gas also as a $c_y$-function for humans.

Our definition of cultural functions does not require that $c_z$-functions of items $x$ for organisms $z$ of species $S$ contribute to the inclusive fitness of those organisms $z$. Hence, $c_z$-functions, like Sperber’s biological and cultural teleofunctions, can have in principle neutral or even detrimental consequences to the survival of the organisms of species $S$. This consequence can be avoided by adding to the definition the clause that $c_z$-functions of items $x$ do contribute to the inclusive fitness of the organisms $z$ of species $S$. We will in this paper not argue for or against adding such a clause, yet in our analysis of biotechnology we will consider only $c_z$-functions that are contributing to the inclusive fitness of human beings.

We call an item with an $a_x$-function an $S$-artefact, an item with a $b_y$-function an $S$-biological item, and an item with a $c_z$-function an $S$-cultural item. Items having an $a_x$, $b_y$ or $c_z$-function for an organism $z$ of species $S$ need not be a part of that organism $z$, as illustrated by some of the examples that we gave above.

Biotechnology can now be characterised as the human ability to select or modify organisms of other species $S$ such that these other organisms become to have items with capacities $\phi$ that are, minimally, human artifactual functions or human cultural functions. These items of organisms become then $H$-artefacts, $H$-cultural items, or more. Moreover, the capacities that are human artifactual or cultural functions, may also be or become biological functions for the organisms of the species $S$ involved. Yet, before embarking on our analysis of biotechnology in such terms, we first give a more general description of how organisms of different species may functionally interact.

4. Symbiosis

Organisms of different species may interact with one another by competing for resources, producing resources for one another and by being resources for one another. We continue with characterising interactions between organisms of two species in functional terms, using the notion of the extended phenotype. We do not aim at capturing all possible types of interactions; we are merely collecting the means to analyse biotechnology. We focus on interactions between organisms of two species in which organisms of one species $S$ benefit from organisms of the second species $S’$. The species $S$ and $S’$ are then in symbiosis and this symbiosis can take at least four forms.

Commensalism: Organisms $z$ of one species $S$ can benefit from the existence or from the behaviour of organisms $z’$ of a second species $S’$ without harming those organisms $z’$. For example, arctic fox (*Alopex lagopus*) follow polar bears (*Ursus maritimus*) for scavenging on the remains of the kills of the polar bears. This commensalistic type of symbiosis can amount to $b_y$-functions. If the item of the organisms $z$ of species $S$— e.g., some behaviour of $z$— by which they are benefiting from the organisms $z’$ of species $S’$ is genetically determined, then making the benefits available becomes a $b_y$-function of that item. Natural selection on the organisms $z$ of species $S’$ will favour the commensalistic symbiosis and affect the genetic make-up of the organisms $z$ of species $S$ accordingly. If the behaviour of the fox to follow polar bears is genetically determined, this behaviour has the capacity to provide the fox with food as a $b_y$-function. Commensalistic symbiosis typically does not change the genetic make-up of the organisms $z’$ of species $S’$ and does not amount to $b_y$-functions: if it makes sense at all to say that the organisms $z’$ of species $S’$ have a genetically determined feature to provide the organisms $z$ of species $S$ with benefits, this feature will not be one that is favoured by natural selection or one that contributes to the inclusive fitness of the organisms $z’$.

Parasitism: Organisms $z$ of one species $S$ can benefit from organisms $z’$ of a second species $S’$ in a way that does harm those second organisms $z’$. Organisms $z$ of one species $S$ can feed on organisms
z of a second species $S$, for instance. A more sophisticated and naster form of such parasitic symbiosis is given by the example of Heteropelma scaposum wasps and Helicoverpa punctigera or Spodoptera mauritia caterpillars: the wasps can use the bodies of the caterpillars as a source for food for their offspring by injecting wasps larvae into the caterpillars. Parasitism, just like commensalism, can amount to $b_S$-functions but not to $b_S$-functions. Making available the benefits provided by the organisms $z$ of species $S$ may become a $b_S$-function of an item of the organisms $z$ of species $S$, yet, letting organisms $z$ of species $S$ take advantage of the organisms $z$ of species $S$ does not become a $b_S$-function of items of the organisms $z$ of species $S$. Rather one may expect that the organisms $z$ of species $S$ will develop features that defend them against parasitism. This second type of symbiosis may therefore change the genetic make-up of both species: natural selection will change the genetic make-up of the organisms $z$ of species $S$ towards parasitism and will change the genetic make-up of the $z$ of species $S$ against parasitism.

In addition to these asymmetrical interactions one has also symmetrical symbiotic interaction, called mutualism. The organisms of two species $S$ and $S$ now benefit from each other’s presence by providing conditions that are mutually profitable. The two species co-evolve and both change genetically as a consequence of the symbiosis. Mutualism can amounts to $b_S$-functions of items of the organisms $z$ and to $b_S$-functions of items of the organisms $z$. More interestingly, by the notion of the extended phenotype, mutualism can make that items of the organisms $z$ of species $S$ have $b_S$-functions for the organisms $z$ of species $S$, and vice versa. By the co-evolution the capacities of the items of the organisms $z$ of species $S$ that are beneficial to the organisms $z$ of species $S$, may become phenotypical expressions of the genetic make-up of the organisms $z$ of species $S$, allowing to argue that these capacities are $b_S$-functions for the organisms $z$ of species $S$.

Mutualism comes in two types.

**Facultative mutualism:** The symbiosis can be lenient: the two organisms are co-evolving and become by natural selection adapted to one another, yet the co-evolution has not changed both organisms in such a way that they can only survive while interacting: the symbiosis does not define niches in which the survival of the organisms of $S$ or $S$ are critically dependent on. An example may be the pilot fish Naucrates ductor that accompany sharks and eat the parasites of sharks. The sharks are a source of food for the pilot fish and the sharks may be taken as pilot fish-biological items—$PF$-biological items—with the pilot fish-biological $b_{PF}$-function of providing food. The pilot fish, conversely, are ridding the sharks of their parasites and can be taken as shark-biological items with the $b_{SF}$-function of protecting against parasites. Yet, at least the pilot fish are not locked-in by the symbiosis; when sharks are not available, the pilot fish may survive by finding food elsewhere.

**Obligate mutualism:** If, however, the mutualistic collaboration does define a niche on which at least one of the two interacting species is fully dependent on, that species is locked-in by the interaction. The example may now be clownfish (Amphiprion ocellaris) that live within anemones (Actiniaria). The anemones are $CS$-biological items of the clownfish, with the $b_{CS}$-function of providing protection against predators, and the clownfish are $A$-biological items for the anemones with the $b_{SA}$-function of removing parasites. These clownfish have evolved in such a way that they have become immune to the nematocysts and toxins of their host anemones, and they may effectively only survive within their host anemone.

When species are considered that are capable to social learning or to intentional behaviour, the four forms of symbiosis can be taken as also involving cultural and artifactual functions. We again consider the four forms of symbiosis we discussed above and assume that the organisms of one species—species $S$—are able to learn socially or behave intentionally.

**Commensalism and Parasitism:** When an organism $z$ of species $S$ intentionally selects or modifies an item of another organism $z$ of species $S$ for making available a capacity of the item, that capacity is an $a_{z}$-function of the item of organism $z$. When a mining engineer intentionally carries a canary down a mine for detecting mine gas, the canary has the $a_{z}$-function of detecting the gas. Given that the canary may not survive the trip into the mine, the symbiosis is a case of parasitism (if canaries are bred for detecting mine gas, the case becomes one of mutualism). When organisms $z$ of species $S$ benefit from other organisms $z$ of species $S$ by some behaviour of the organisms $z$ of species $S$ that they—the $z$ organisms—copy from one another, then making the benefits available becomes a $c_{z}$-function of that behaviour. If the arctic fox’ behaviour to follow polar bears for scavenging on the bears’ kills, is a behaviour that is socially reproduced among arctic fox, the capacity to provide the fox with food is a $c_{PF}$-function of that behaviour. Moreover, the polar bears themselves have the $c_{PF}$-function of producing carcasses for the fox, and the symbiosis is a case of commensalism.

**Facultative and Obligate mutualism:** When organisms $z$ of species $S$ culturally or intentionally benefit from organisms $z$ of species $S$, and the interaction also benefits the organisms $z$, then the capacities of the organisms $z$ that are use to the organisms $z$ of species $S$, may become also biological functions of the organisms $z$ of species $S$. When blueberries (Vaccinium myrtillus) are culturally and/or intentional planted by humans for eating the berries, the planting behaviour has the $a_{PF}$- and $c_{PF}$-functions of making the berries available for human consumption and the plants themselves have the $a_{PF}$- and $c_{PF}$-functions of making the berries available for human consumption. The benefit of the plants in this mutualistic symbiosis—it is a case of facultative mutualism since the plants can live also without this use by humans—is that they are repeatedly being planted (and cared for) by humans. Its capacity of having berries then becomes a capacity that contributes to the plant’s inclusive fitness, that is, this capacity becomes a $b_{PF}$-function as well. Moreover, if humans and blueberries co-evolve in a more enduring mutualistic interaction, the capacity of humans to benefit from blueberries may become a phenotypical expression of the genetic make-up of the plants, and in this way human behaviour and humans themselves may acquire the $b_{PF}$-function of distributing the blueberries’ seeds and providing for light and nutrition. Considering human beings as items that have biological functions for mundane plants like blueberries may seem odd, yet it is the merit of Sperber (2007) to draw this conclusion explicitly. He gives a number of examples of symbiotic relationships between humans and organisms such as domesticated and bred animals and plants, in which human beings have become instrumental in the survival of the organisms. For instance, cereals and dogs have been living in mutualistic symbiosis with humans for a substantial time (e.g., Diamond, 2002; Call, Brauer, Kaminski, & Tomasello, 2003), allowing to argue that the genetic make-up of both these organisms and the human beings have genetically co-evolved and changed in support of the symbiosis, and allowing to argue that not only these organisms have cultural and artificial functions for us but also that we have biological functions for cereals and dogs. Humans display behaviour that is beneficial for the survival of cereals and dogs—we clear forests and upgrade soil for the cereals to grow on; we collect food for dogs and help them with rearing their puppies—and have become in that way $C$-biological and $D$-biological items, as much as the cereals and dogs have become $H$-artefacts and $H$-cultural items. The fact that we intentionally and culturally have changed plants and animals, even to such extents that those plants or animals have lost the ability to survive independently from us, is not refuting this conclusion, but merely showing that the mutualistic symbiosis can be obligate mutualism. Sperber’s example of
seedless fruits illustrates this last point. Although humans have altered some plants substantially, as in the case of seedless fruits, where the plants involved cannot reproduce anymore by way of the distribution of seeds, these plants are still reproducing but now with the help of humans.

Domestication, breeding and the altering of organisms brings us in the domain of biotechnology, and with the help of our functional descriptions of interactions between organisms of two species we can identify three routes by which biotechnology typically proceeds.

5. Three functional routes for biotechnology

Human beings use organisms of other species for all kinds of goals. We use plants and animals as sources of information, say about how the seasons are progressing, and this could count as commensalism. Or we collect them for feeding on them, and this would count as parasitism or mutualism. These uses may presuppose sophisticated knowledge from our side about the organisms, and may therefore be taken as instances of technology. Yet, biotechnology in its more paradigmatic forms, as with other types of technology, involves not merely the using of items but also the making of those items. Biotechnology refers typically to practices in which organisms are modified, ranging from manipulating individual organisms, to the domestication, breeding and genetic engineering of species. We therefore will ignore commensalism, and focus on parasitism and mutualism to characterise biotechnology.

The first route by which biotechnology can proceed in our functional analysis is the parasitic route. On this route an item x of an organism z of a species S is selected or modified for a capacity useful to human purposes, but the item x is not reproduced. This item x then has that capacity φ as an artifactual aφ-function. The capacity φ of item x may or may not be a biological bφ-function for the organism z, yet φ is not a bφ-function due to the parasitic use by humans since x is not reproduced by humans for the used capacity φ.

When the use of the item x is communicated between humans and repeated for other organisms z’ of species S, then the capacity may become also a human cultural cφ-function. Biotechnological parasitism operates on instances of species: human use has an impact on particular organisms z of species S but typically not on lineages of organisms of the species S.

A shorthand description of this first route is as follows:

Biotechnological parasitism:
Item x of organism z of species S has a capacity φ as an aφ-function; this capacity φ is possibly a cφ-function but typically not a bφ-function.

Examples are the use of retinas of cows for making vaccines, the use of canaries in mines (as long as canaries are not reproduced for this use), incidental animal testing on, say, primates, and genetic engineering outside the germ-line of organisms.

The second route for biotechnology is the one of facultative mutualism: an item x of organisms z of a species S is selected or modified for having a capacity φ useful to human purposes. This item x then has that capacity φ as an artifactual aφ-function. Before the human interference, this capacity φ of item x typically is not a biological bφ-function for the organism z—in the case of modification the capacity φ may not have existed before the interference. Yet on this second route the organisms z are deliberately reproduced for having more organisms with capacity φ. Organisms z that are the result of this reproduction have this item x as a phenotypical expression of their genetic make-up. And because the organisms z are selected for this item by human interference, the capacity φ becomes a biological bφ-function for the organisms z in the context of the human selection of the organisms. The use of the item x for the capacity φ is communicated between humans and repeated for other organisms z of species S, hence the capacity φ becomes also a cultural cφ-function. Moreover, on this route, the capacity φ can also be a biological bφ-function for the organisms z when human interferences with the organisms stop: the organisms z can then still reproduce and the capacity φ may still contribute to the inclusive fitness of the organisms z. We call this route for biotechnology facultative mutualism because it establishes mutualistic symbiosis that changes the genetic make-up of the organisms z of species S—possibly to such an extent that a new species S’ is created—yet does not lock-in these organisms—the organisms may survive and reproduce independently of human interference and then still reproduce the item with the capacity φ. Biotechnological facultative mutualism operates on the level of lineages of organisms z of species S (or S’).

The shorthand description of the second route is as follows:

Biotechnological facultative mutualism:
Item x of organisms z of species S has a capacity φ as an aφ-function, a bφ-function and a cφ-function; when human interaction with the organisms z stops, the capacity φ may still be a bφ-function.

Examples are livestock that is kept in the wild, like the Bos taurus ibericus (Morucha variety) well known for the quality of their meat, or some commercially genetically engineered crops, like Bt corn, which is a variant of genetically altered corn to express the bacterial Bt toxin poisonous to insect pests.

The third route is biotechnological obligate mutualism: an item x of organisms z of a species S is selected and manipulated for having a capacity φ useful to human purposes. This item x then has that capacity φ as an artifactual aφ-function. Before the human interference, the capacity of item x may or may not be a biological bφ-function for the organism z, yet the organisms z are again deliberately reproduced for having more organisms z with item x with capacity φ. Hence, the capacity φ becomes a biological bφ-function for the organisms z. The use of the item x is communicated between humans and repeated, so the capacity φ becomes also a cultural cφ-function. But now, in contrast to the second route, the capacity φ cannot be a biological bφ-function for the organisms z when human interferences stop: the organisms z can then no reproduce and thus will not have anymore the capacity φ as a biological bφ-function. The used organisms are locked-in the mutualistic symbiosis with humans, motivating our choice to call this third route biotechnological obligate mutualism: it changes the genetic make-up of the organisms z of species S—typically to such an extent that a new species S’ is created—that cannot survive or reproduce independently of the human interference. Biotechnological facultative mutualism operates on the level of lineages of organisms z of species S (or S’).

The shorthand description of the third route is:

Biotechnological obligate mutualism
Item x of organisms z of species S has a capacity φ as an aφ-function, a bφ-function and a cφ-function; when human interaction with the organisms z stops, the capacity φ is not a bφ-function.

Examples are dairy cows, for instance, the Holstein Friesian, a breed known as the world’s highest production of dairy products, which are not able to survive when we stop milking them; or genetically engineered Escherichia coli bacteria that are used for making biodiesel, and that can live only in artificial conditions maintained by humans (Cohen, Chang, Boyer, & Helling, 1973).

These three functional routes probably do not exhaust the whole spectrum of ways in which biotechnology can proceed. The routes, for instance, limit biotechnology to interactions in which the items of the used organisms that have aφ- and cφ-functions are
reproduced by genetic mechanisms. It may, however, also be possible that social learning among the manipulated animals reproduces the items with $a_{IR}$ and $c_{IR}$-functions—we briefly consider an illustration of this alternative route in the next section. We ignored, as said, also a possible commensalistic route for biotechnology. Such a route would be one in which humans modify organisms for $a_{IR}$ and $c_{IR}$-functions without in any way harming or improving the survival or reproduction of the organisms involved. In principle such a route can be imagined, where the modification is not affecting the organism—say, when adding in some experiment junk DNA to the genotype of some organism that lives in the wild with the mere aim to see if it can be done. In this paper we are however concerned with biotechnology, and assume that the modification is meant to serve practical goals. Therefore we assume that, when the modification is not harmful for the organism—that is, when the parasitic route of biotechnology is not taken—, then humans have reason to keep the modified organism available to realise the set goals. And already the mere act of feeding the organisms and providing the conditions to letting them reproduce, will make the modification a case of one of the mutualistic routes of biotechnology. Further work may, finally, reveal that the three routes that we did describe can be analysed to consist of separate (sub)routes. Yet, with our three routes for biotechnology that we did define, we are already in the position to analyse the controllability of the organisms involved, and to consider the particularity of genetic engineering.

6. Dissemination of biotechnological organisms

Organisms may disseminate beyond the confines of their original habitats and become introduced into ecosystems of which their species is originally not a part. Such organisms are called exotics in ecology, and may disrupt those ecosystems even to a point that human well-being becomes endangered. Organisms that are the products of biotechnology may also be introduced in ecosystems in which their modified species is originally not a part, and be as exotics equal disruptive. This possibility is an incentive to control the dissemination of biotechnological organisms, specifically by the responsibility felt by humans since the organisms are created by humans. With the analysis as given in the previous section, it can be shown that the occurrence of the threat of dissemination of biotechnological progeny is inherent to the facultative mutualism route: mechanisms to prevent dissemination are part of the parasitic and obligate mutualistic routes, whereas the facultative mutualistic route systematically creates the conditions for this dissemination.

The parasitic route: When humans on the parasitic route of biotechnology select and modify items $x$ of animals and plants for some useful capacity $\phi$, reproduction of those organisms $z$ is not an inherent part of the interaction between humans and the organisms $z$. The interaction between humans and organisms is fully aimed at realising human purposes and not at benefits for the organisms. The organisms are not surviving the use, the modifications involved are damaging the changes of their survival, or the modifications are not reproduced, say, because the changes are simply of no value to the organisms $z$. Trees are felled for wood, and then simply stop to exist as organisms that reproduce. Retinas of cows are suitable for making vaccines, but there are no cows that afterwards live on with retinas contaminated by human pathogens. And the chimpanzees that in scientific research are taught to communicate by sign languages are not able to teach that ability to other members of their species. Surprising exceptions may occur—when released from captivity a dolphin started to teach the ability of “tailwalking” on water to wild dolphins, even though the dolphin that was doing the teaching may merely, during its captivity, have seen other dolphins do this trick as taught by humans. We can describe this particular exception as the dissemination of a human cultural $C_{IR}$-function of dolphins as a dolphin cultural $C_{IR}$-function. Yet typically organisms used by us on the parasitic route are locked into this use. Dispersion is avoided by the focus on human purposes against benefits for or reproduction of the organisms; and parasitism may even be inherently blocking dissemination when these organisms are not surviving the human use. There may be other reasons—including ethical ones—for opposing this route of biotechnology, but the threat of an uncontrolled dissemination of the organisms used is not a typical disadvantage of parasitic biotechnology. This type of biotechnology may thus be seen as relatively harmless to existing ecosystems and the related human well-being.

The obligate mutualistic route: On the two mutualistic routes of biotechnology reproduction of the organisms $z$ is part of the use by humans of items $x$ of those organisms. The items $x$ are selected and modified for the use of some of their capacities $\phi$, and then made available over time via the reproduction of the organisms $z$. Dissemination of these organisms $z$ with the modified item $x$ then becomes a clear possibility. In the obligate mutualistic route this dissemination is however checked because the modified organisms $z$ are inherently locked into the obligate mutualistic use. Consider for instance dairy cows. The udders $x$ of cows $z$ have been selected by humans for the useful capacity $\phi$ of producing milk, and are by breeding modified to producing even more milk than is effectively necessary to feed the cows’ calves, creating the breed of, say, Holstein cows. The original capacity $\phi$ of producing milk is a biological $b_{IR}$-function for the original cows, and the resulting capacity $\phi$ of producing more milk is a biotechnical $a_{IR}$- and $C_{IR}$-function for humans. The capacity $\phi$ of producing more milk is also a biological $b_{HC}$-function for the Holstein cows, for it is a capacity that is a phenotypical expression of the Holstein cows’ genotype that within the context of dairy farms contributes to the cows’ inclusive fitness. Yet, this new capacity $\phi$ is a biological $b_{HC}$-function for the Holstein cows only within the context of those dairy farms. Holstein cows that are set free to live, like the original cows, in the woods without human attendance, would have a distinct disadvantage by this capacity $\phi$ of producing more milk, and would not survive and not reproduce as Holstein cows (Rauw, Kanis, Noordhuizen-Stassen, & Grommers, 1998). The same holds for seedless grapes. The new feature is interesting from a human point of view and a $b_{HC}$-function for the grapes. Nevertheless, if human beings do not reproduce the grapes’ stocks, the seedless grapes would cease to exist. Following this biotechnological route, the chances for dissemination of the modified organisms $z$ are low because the possibility is slim that these organisms can survive in existing ecosystems for more than one generation. Biotechnology along the obligate mutualistic route is thus inherently avoiding dissemination of the modified organisms. Again there may be other reasons for opposing this route of biotechnology, but the threat of an uncontrolled dissemination of the organisms involved is not the disadvantage.

The facultative mutualistic route: The problematic route is the facultative mutualistic one. The organisms $z$ of species $S$ with the item $x$ with a capacity $\phi$ that is an $a_{IR}$- and $C_{IR}$-function for humans, is again developed by breeding or by more modern means. And this capacity $\phi$ is again a biological $b_{HC}$-function for those organisms because this capacity $\phi$ is a phenotypical expression of the organisms’ genotype that contributes to their inclusive fitness. But now, when the organisms are outside the symbiotic relationship with humans,

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1. When trees, cows and chimpanzees are bred for the uses mentioned, one is not dealing anymore with the parasitic route but with the mutualistic routes also discussed in this section.

the organisms can still reproduce. The capacity $\phi$ may stop to be a $b_x$-function but because the organisms having this capacity still reproduce, the capacity is being disseminated. Moreover, if the capacity $\phi$ remains to be a $b_x$-function by contributing to the organisms' $z$ inclusive fitness, the capacity $\phi$ even contributes to its dissemination. The capacity $\phi$ is thus not locked-in and dissemination is inherent to the biotechnological route of facultative mutualism: the threat that the organisms $x$ are introduced as exotics in existing eco-systems is realistic. This is not a problem for specifically modern biotechnology and its GMOs. Every feral organism, that is, every organism that has escaped from a humanly controlled and closed context, and became introduced in ecosystems of which it was originally not a part, can cause many and important problems to those ecosystems, contributing to the extinction of indigenous species. One of the most outstanding examples could be the dissemination of domesticated cats over the world. The kind of relationship that we have established with cats is different from other domesticated species. Cats are "exploitive captives", that is, they do not usually suffer from the relationship as much as those other domesticated species. Humans and cats both gain from the interaction: humans gain because of the cat's ability as rat-catchers, and cats gain shelter and feeding. Their abilities to hunt were very valuable, until the point that Europeans decided to travel with cats in their ships. Sealers and whalers left domesticated cats free in some areas where there were not cats before. Those cats reproduced and spread in new areas until the point of being a threat to native species. The main solution in those areas where cats become a problem for native species has been to exterminate those cats, by hunting or poisoning them or by neutering (Nogales et al., 2004). Another historical example could be the goats put ashore by Captain Cook in New Zealand. The idea was that goats could be a source of emergency food in case of shipwreck or for ships out of fresh meat. Those animals became feral and reproduced into large populations, eating all palatable plants and causing depletion of soils and accelerated erosion. The New Zealand Forest Service exterminated more than 300,000 goats between 1951 and 1958.

7. Genetic engineering and the uncanniness of GMOs

Genetic engineering, being yet another form of biotechnology, has on our analysis the same advantages and disadvantages as any other form of biotechnology. For genetic engineering the three functional routes are available, two with in-built mechanisms to prevent dissemination of its progeny, and one which creates the conditions for this dissemination. One can use organisms parasitically in genetic engineering, say, by changes outside the germ line of those organisms that modify in principle not the next generations of those organisms. One can in genetic engineering create GMOs that can reproduce independently from, say, controlled laboratory conditions, introducing the possibility of an unchecked dissemination of similar organisms. And in engineering one can create GMOs that can reproduce only under those controlled laboratory conditions, avoiding dissemination. What, then, makes GMOs different to modified organisms produced by more traditional forms of biotechnology, such as breeding? Why are GMOs controversial? Drawing now on work by Alfred Nordmann (2008), we will argue that this controversiality may be due to the undetectable nature of GMOs. By being of submicroscopic size or by being macroscopically similar to unmodified organisms, uncontrolled and disruptive dissemination of GMOs will have the characteristic of untraceable natural disasters.

Alfred Nordmann, in analysing primarily nanotechnology, developed the notion of 'naturalised technology' to capture what he calls a "curious regressive inversion of the relation between humans, technology, and nature." Modern technology stops to be a means by which we human beings control nature for our purposes, but increasingly "dissolves into nature and becomes uncanny, incomprehensible, beyond perceptual and conceptual control." (2008, p. 173) Nanotechnologies are examples of such naturalised technologies, but Nordmann develops the notion by focussing on genetic engineering of foods. "[T]he technical intervention that makes for a genetically modified plant [...] remains essentially inconspicuous to human senses" and, on some accounts, remains to be so as when "the genetic modification [...] persists[s] and continue[s] to act as it passes [as food] through our bodies to some untraceable place in the environment." (2008, p. 176) And when genetic modifications indeed remain to act in our bodies and the environment, then what initially was meant to be a technological act to control nature to our benefits, is creating "a pervasive technical environment that appears to be just as uncanny as brute nature with its germs, viruses, or bacteria [...]." (2008, p. 176) Naturalised technology is according to Nordmann technology that creates technical agency that we may know to exist but cannot possibly perceive or control.

Genetic engineering in general may have for a large part this character of naturalised technology. The DNA that has been modified is beyond the thresholds of perception and the GMOs it produces may be macroscopically indistinguishable from other non-modified organisms and can as such blend with those other organisms beyond detection. Genetic engineering may in this way change the natural environment to one that consists of organisms contaminated by modified DNA, even though we humans do not have the practical means to perceive it as an environment different to the natural environment. This makes genetic engineering epistemologically different from more traditional biotechnology, since the organisms produced by traditional biotechnology are by their macroscopic sizes typically distinguishable from other organisms, even if they disperse beyond control. European livestock set free in other areas on earth may be a pest and be a serious pest, but still a pest that is recognisable as such. But when submicroscopic GMOs and modified DNA are out of control and harmful for human well-being, their dissemination may best be compared with pests like smallpox and measles, and more, recently, influenza A-H1N1, with all its consequences and fears.

Whereas the products of traditional forms of biotechnology are thus recognisable as exotics when they disseminate in ecosystems, GMOs defy from an epistemic point of view the distinction between exotics and naturally occurring organisms. For traditional biotechnology we still have the practical possibility to at least try to exterminate disseminating modified organisms when these organisms affect human well-being, as we do with the feral cats and goats. But genetic engineering may leave us empty handed. Genetic engineering may create GMOs that start to disseminate, and when that affects human well-being, extermination of those GMOs is practically speaking not even an available option.

Moreover, with our analysis of biotechnology it seems evident that GMOs will disseminate. If the biotechnological route of facultative mutualism is adopted in genetic engineering, GMOs can reproduce also independently of their symbiotic relationships with humans, disseminating the capacities $\phi$ for which they are modified; after their use these capacities may even remain biological $b_{o_{\text{GM}}}$-functions of the GMOs, thus propelling reproduction and dissemination.

8. Strategies against dissemination and the uncanniness of GMOs

European citizens are reluctant to accepting GMOs and the EU has tried to answer their concerns by developing restrictive legisla-
tion. Since the early 1990s EU legislation exists with the goal of protecting public health and restricting contact of GMOs with the population and the environment. This legislation is considered to be one of the strictest in the world and the main concern here is to try to control dissemination: GMOs should not leave the laboratory in the experimental phase, and genetically manipulated crops should be isolated to designated fields in the commercial phase. Since 2004 there are several legal instruments in Europe for developing traceability and labelling rules. For instance, the Directive 2001/18/EC concerning the intentional introduction of GMOs into the environment without specific containment measures, tries to deal with releases of GMOs for experimental and commercial purposes. Finally the Regulation (EC) No 1830/2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products manufactured with GMOs, tries to facilitate the control and verification of labelling claims, as well as “targeted monitoring of potential effects on health and the environment, where appropriate; and withdrawal of products that contain or consist of GMOs where an unforeseen risk to human health or the environment is established” (EU policy on biotechnology. European Commission. Environment DG, 2006). The European Commission imposes temporal and spatial limitations for the use of GMOs in areas of seed production, taking into account pollination characteristics and seed longevity. Nevertheless, pollen dispersal is quite difficult to control, and even when there is no conclusive evidence about the ecological consequences of seed contamination with GMOs, the EU Scientific Committee on Plants states that contaminations are unavoidable. Complete isolation of GMOs is not possible and GMOs can contaminate original organisms.

Our analysis of biotechnology can be used to understand and articulate the EU efforts to prevent dissemination and improve traceability of GMOs. The uncanny character of GMOs consists of their undetectability when disseminating, and the EU aims to deal with this both by making GMOs traceable and by controlling their dissemination. Labelling indeed makes GMOs traceable, allowing again to exterminate, or to try to exterminate, GMOs that have disseminated beyond the confines to which they were meant. Controlling dissemination moreover minimises the chances that GMOs become exotic that have to be considered as pests that damage our environment and threaten our well-being.

With our analysis the EU efforts can also be assessed and developed. First, the aim of controlling the dissemination of GMOs is by our functional analysis of biotechnology not a matter of merely isolating GMOs to designated fields. This aim can reasonably be realised when genetic engineering is limited to the biotechnological routes of parasitism and of obligate mutualism, not allowing it to take the route of facultative mutualism. The two first routes have inherent mechanisms to prevent the produced GMOs to reproduce independently of the biotechnical symbiotic relationship with humans, turning physical, spatial or temporal barriers into effective measures to isolate these GMOs: the probability that a GMO disseminates beyond control is then equal to the probability that it simultaneously can cross given barriers and evolve from an organism that cannot reproduce outside the biotechnological symbiosis to an organism that can reproduce independently. Assuming that the occurrence of these two events are independent from one another, the overall probability to dissemination may indeed be taken as conclusively small. The third route of facultative mutualism creates, instead, GMOs that can immediately reproduce independently of the biotechnical symbiotic relationship with humans, and thus increases the probability that a GMO disseminates to only the probability that it can cross the barriers erected. Allowing genetic engineering to take this third route would therefore be counter to the EU aim of controlling the dissemination of GMOs, since it implies disregarding a barrier to dissemination that is available in biotechnology. Second, Alfred Nordmann’s (2008, p. 176) discussion of genetically modified food, shows that the EU aim of making GMOs traceable may better not be limited to the GMOs themselves. The EU already extends the tracing to also the products manufactured with GMOs by considering also food and feed products. Yet this tracing can reasonably be extended also to the consumers of those products. Modified DNA may not stop to have effects on its environment when it is digested by humans or by livestock, allowing in principle GMOs to still manifest themselves as uncanny entities.

Banning facultative mutualism for genetic engineering seems feasible. Such a measure would not mean giving up on the prospect of this new form of biotechnology since the parasitic and obligate mutualistic routes are still available for genetic engineering. And the route of obligate mutualism still allows for creating reproducing GMOs and also allows for keeping GMOs in the open, for instance, as crops and bacteria that do not have the ability to reproduce themselves. Making GMOs traceable beyond digestion may be less feasible, especially when human consumers are concerned. For livestock however means may be made available or already be present by the different registrations systems for feed products in agriculture.

9. Conclusions

In this paper we showed that a functional analysis can provide a general framework for understanding biotechnology in its different realisations. The analysis applies equally to traditional forms of domestication and breeding, as to contemporary genetic engineering; what makes genetic engineering particular are epistemic and practical problems in tracing and controlling the dissemination of the GMOs it produces.

We identified three general functional routes in which biotechnology can proceed, routes in which humans modify organisms in ways that they can perform artifactual functions. All three routes create symbiotic relationships between human beings and the modified organisms, and we labelled the routes by the type of symbiosis that is established. Two of the routes have in-built mechanisms for preventing the progeny of the modified organism to disseminate the capacities associated to the artifactual functions for which they are modified or used. On the parasitic route the organisms concerned typically do not reproduce the capacities associated to these artifactual functions, for instance, because the organisms’ chances to reproduce diminish by the interaction with humans or because the organisms do not survive at all. On the obligate mutualistic route the capacities associated to the artifactual functions become biological functions of the modified organisms, but these organisms can reproduce only when staying in symbiotic interaction with humans. Hence, dissemination of the modified organisms, and thus dissemination of the associated capacities, occurs only under humanly controlled circumstances. The third route of facultative mutualism can however lead to situations in which modified organisms disseminate out of human control. On this route the capacities associated to the artifactual functions become biological functions of the modified organisms, and now the organisms can reproduce also when they are not in symbiotic interaction with humans. Uncontrolled dissemination of the modified organisms, and dissemination of the capacities for which they are modified, can therefore occur. This conclusion holds equally for genetic engineering and more traditional forms of biotechnology. Yet, because of the progeny of genetic engineering can escape our perceptual and conceptual control, the dissemination of GMOs may become practically a threat to the environment and to human beings that is impossible to contain or battle. This uncanny character of GMOs is characteristic (though not exclusive) to genetic engineering: disseminating progeny of traditional forms of biotech-
nology are typically identifiable and in principle exterminable as exotics.

In this paper we focused on the dissemination of the progeny of biotechnology and of GMOs in particular. We did not discuss ethical or other reasons to be critical or affirmative to biotechnology or genetic engineering. There are clearly numerous of such other considerations, ranging from general points that we should not use or abuse other organisms for our purposes, to specific issues that farmers should not be made dependent on a constant production of genetically engineered seeds, or ranging from maintaining or improving our life-standards in a world with diminishing resources, to curing awkward diseases. Our contribution is therefore directed to one aspect of the general debate on biotechnology. With our general analysis we hope to have shed new light on the on-going academic and public controversies around genetic engineering, and provided elements to the development of efficient regulation for controlling dissemination of GMOs: by banning the biotechnological route of facultative mutualism and by making GMOs and their effects on the environment and on human beings traceable, genetic engineering may be perceived as a less uncanny human enterprise.

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