# Evolution, crime science and Terrorism: The case of Provisional IRA Weaponry

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## Abstract

This chapter adopts a long-term, evolutionary perspective, bringing together crime science and ideas from cultural and biological evolution. By way of illustration it discusses in detail how evolutionary processes operating at the technological and tactical level played out in a specific, prolonged period of conflict between the Provisional Irish Republican Army (PIRA) and the UK security services including the police and the military from 1970-1998. This conflict saw not just a steady evolution of terrorist attack techniques and weapons technologies including improvised explosive devices (IEDs), but a *co*-evolutionary arms race with the security side. The advantage of an evolutionary perspective on terrorism and counter-terrorism is that it helps us understand and exploit past history, beneficially influence present risks, and prepare for future challenges. The *co*-evolutionary perspective confers additional benefits in highlighting the simultaneous consideration of attack and defence, move and counter-move, and the symmetries and asymmetries between the opposing parties in a complex adaptive system. More generally, it enables us to detach ourselves from immediate battles and view the conflict strategically. Specific practical implications of the anticipation of counter-moves, handling arms races and drawing on design are discussed. The (co-)evolutionary approach can equally apply to the struggles with organised crime or indeed to any offending which develops and exploits technological and operational advances.

Keywords: terrorism, counter-terrorism, evolution, arms race, crime prevention, adaptation.

## Introduction

Crime and terrorism are not static problems. They change on timescales from days to decades. In part, this flux stems from offenders adapting to exploit opportunities afforded by exogenous social and technological developments in society, and to cope with threats from other offenders. But significantly too it derives from *arms races* between offenders and those on the security side. On the security side, however, the consensus among change-minded commentators has been that 'contemporary crime control policies are hopelessly static' (Cohen et al., 1995:216; see also Dietl, 2008). Ekblom (1997, 2016a) argues that to win campaigns rather than merely individual battles against criminals and terrorists, we must routinely *out-innovate* adaptive offenders against a background of technological and social change that may first favour one side, and then the other. The classic example is Shover's (1996) study of safes and safe-breakers, where new, emerging technologies including combination locks, cutting tools, new hardened alloy casings and so forth flipped the advantage back and forth between the opponents.

Accounts of longer-term change and innovation processes have often drawn on *evolutionary* themes, as does the present chapter. Such themes extend beyond conventional, biological evolution to include cultural, and specifically technological, counterparts. Evolution covers processes highly relevant to the strategic view on crime prevention and counter-terrorism – adaptation, innovation and improvisation. As we shift focus from casual opportunistic offending and its short-term decision/action cycles to that which is persistent, motivated and perhaps well-resourced, these factors become salient.

Crime science has only recently begun to incorporate evolution – see Cohen et al. (1995), on theft; Ekblom (1997, 1999) and Brown (2016) on arms races; Felson (2006) on crime and nature. Roach and Pease (2013) supply an excellent introduction to the field which argues the case for linking evolution with situational prevention in particular and with social science in general. Sell (this volume) presents a guide for using evolutionary theory to understand a given kind of crime. A useful attempt to link more traditional criminological topics with evolutionary thinking is by Durrant and Ward (2012). If studies connecting evolution and crime are rare, those combining evolution, terrorism and crime science are scarcer than a fossilised Denisovan finger bone. Ekblom et al. (2016) apply explicit evolutionary psychology perspectives to illuminate and enhance situational prevention of terrorism. Ekblom (2016) addresses terrorist/security arms races from the perspective of cultural and technological evolution, innovation, and design; the evolution of offender rationality (2017a); and the evolution of technology (in press 2017b).

This chapter blends a crime-science approach to prevention, with ideas from cultural and biological evolution, covering both the entities that are evolving, and the environment or ecosystem to which they are adapting. We show how, together, they can provide a fresh perspective and a richer understanding, supporting attempts to control terrorist attacks that are more strategic and change-oriented than before.

We discuss in detail how evolutionary processes operating at the technological and tactical level played out in a specific, prolonged period of conflict between the Provisional Irish Republican Army (PIRA) and the UK security services including the police and the military from 1970-1998. This conflict saw not just a steady evolution of terrorist attack techniques and weapons technologies including improvised explosive devices (IEDs), but a *co-*evolutionary arms race with the security side.

From 2010 to 2012, a team of researchers at Pennsylvania State University and elsewhere sought to understand the behavioural underpinnings of PIRA's improvised explosive device creation and implementation (Gill, Horgan and Lovelace, 2011). It led to a series of publications regarding creativity and innovation (Gill, 2017; Gill et al., 2013; Johnson et al., 2013), red-team blue-team interactions (Asal et al., 2015; Gill, Piazza and Horgan, 2016) and the social networks that created the IEDs (Gill et al., 2014, Gill and Horgan, 2013). The papers built upon the then relatively underdeveloped research ideas behind creativity and innovation and terrorist behaviour. Collectively the papers utilised insights from diverse disciplines including organisational and industrial psychology and political science and they helped identify the individual, network, organisational and environmental traits that combined to make the ground for PIRA's innovation so fertile.

This chapter re-purposes the findings from these research papers to help illustrate the evolutionary dynamics behind these processes. The aims are first, to illustrate evolutionary thinking and second, to demonstrate how it can organise practically and theoretically relevant empirical knowledge, identify significant gaps and aid the adoption of more strategic responses to such arms races. Our emphasis is thus on cultural/technological evolution rather than, say, the evolutionary psychology of offending, which Ekblom et al. (2016) and Sell (this volume) cover elsewhere. The evolving entities or units of interest here comprise individual weapon designs and techniques.

The next two sections cover the basic mechanisms of evolution, and how evolving entities relate to their environment by a combination of adaptation and niche construction. After that there are sections on: higher-level processes of change, centring on accelerants of evolution; the 'flying leaps' of advancement feasible in cultural/technological evolution; and co-evolutionary arms races. The concluding section identifies lessons for policy and practice in terms of the importance of anticipation, running arms races and the employment of design, not only in solving complex security problems but in reframing them.

Before proceeding further, we should note that some of the links to evolution we draw on are by analogy, helping just to broaden thinking in crime science; but others can be deemed formal equivalents between biological evolution and technological/cultural counterparts. The latter of course differs by including purposive and anticipatory processes rather than being mindless, goalless and confined to local maximisation of survival/reproductive benefit. This chapter has for reasons of space and audience tended to slide between the two but proper research and application across the disciplines needs to be done carefully and with precision. Good guides to the relationship between biological and cultural evolution are in Laland (2017) and Mesoudi (2017).

## Evolution: basic mechanisms

The fundamental process of biological evolution comprises:

1) *Variation* of physiological, anatomical and behavioural traits among the population of a species

2) *Selection* through differential survival and reproductive success of organisms possessing those trait variants best adapted to the relevant habitat – living conditions which may challenge individuals through competition and conflict over territory, resources or mates, and predation

3) *Transmission or inheritance* of those advantageous traits through replication across successive generations, so they become more prevalent in the population, perhaps eliminating less fit alternatives and leading to divergent species adapted to different habitats.

This model has been extended from what is nowadays understood as gene-based evolution to cover evolution based on behavioural and symbolic processes (Jablonka and Lamb, 2014) including linguistic and cultural processes. While these follow the same 'evolutionary algorithm' (Dennett, 1995) of variation, selection and transmission, they are mediated by very different underlying mechanisms of increasing, and nested, complexity (Vinicius 2010). Cultural evolution (including the more specific evolution of technology and the explicit use of design) can be viewed as the variation, selection and replication of 'memes' (Dawkins, 1976; Blackmore, 1999; Aunger et al., 2000) or more generally the operation of social learning processes in cultural evolution (Laland, 2017; Mesoudi, 2017). In some ways analogous to DNA-based genes, memes are ideas, designs for tools and weapons, tunes, behaviours, and wider complexes like religions or moral causes. They are seen as competing for space in the minds of individual humans and for opportunity to be replicated by us and our machines.[1]

We now cover these three basic mechanisms in turn, while acknowledging the interactions between them.

## Variation, creativity and innovation

Variation provides the raw material of evolution. In biological evolution variation derives mainly from mutations in DNA copying, and recombination/mixing of parental genes during sexual reproduction. In multicellular organisms, such variation is expressed during the development process from fertilised egg to adult. This is where the information in the genotype (the 'replicator' or blueprint) becomes expressed in a phenotype, the real-world 'vehicle' through which the genes are tested against the environment. Cultural evolution generates variety through several mechanisms operating on different scales (Godfrey-Smith, 2012) from localised imitation to major shifts such as the Neolithic farming revolution.

Imitation is widespread – indeed, the PIRA's pioneering use of car bombs was imitated worldwide. Cultural variety can come from 'blind' copying errors in imitation (which may not always be advantageous, e.g. in recipes for explosives), or from generative processes of creativity and innovation. Creativity generates novel ideas; depending on one's viewpoint it can, of course, be malevolent (Cropley et al., 2010 cover its 'dark side'). PIRA showed both imitation and malevolent creativity in operation (Gill, 2017; Gill et al., 2013). But in practice imitation and creativity overlap more than we think. According to Jablonka and Lamb (2014) the former involves a significant element of *reconstruction.* Thus imitators must translate the target behaviour from perceived movements into their own hierarchy of movement control commands at one end of the scale, or reverse-engineer some tool or weapon at the other.

*Innovation* at the cultural level is a more complex process which takes creatively-generated ideas through to practical applicability (cf. Dolnik, 2011; Ekblom and Pease, 2014; HM

Treasury, 2005). Innovation may also involve selection (e.g. through iterative development trials where unworkable designs are weeded out) and replication (manufacture and perhaps deployment). Incidentally, this deliberate, self-aware process of design improvement more closely resembles *artificial* selection of the kind used to improve breeds of cattle, or wheat. And, more broadly speaking, there are interesting resonances between replication and innovation in crime-prevention practice: Ekblom (2002, 2011), building on Tilley (1993), notes that every replication involves some innovation in adjusting the action to new contexts.

Given the circumstances PIRA faced (relatively limited resources, constant threat from the security services and Loyalist opponents), *improvisation* was the norm. Gill (2016) provides an extensive discussion of this concept. Here, we can view it as highly constrained innovation: rather than bottom-up creation, it involves using 'off-the-shelf' products or materials with little modification, only the production of novel combinations and/or some repurposing; likewise, trialling and improvement may be limited. In fact, this is rather like what happens in the early stages of emergence of a novel trait in biological evolution. An example is where a bird's feathers, probably originally acquired for insulation, became repurposed to enable flight. This is known as 'exaptation'. In more advanced species like proto-birds, *exploratory* behaviour, e.g. trying out lift from feathers, often serves to 'pilot' more systematic evolution. If the feathers work sufficiently well to soften falls or prolong a glide towards prey or away from predators, natural selection can take more systematic improvements in hand, eventually permanently embedding feather-growing and feather-using tendencies in the genes in a process called 'facilitated variation' (Laland et al., 2015).

Evolutionary progression occurs in steps of varying size. Large leaps forward are rare in biology (e.g. from single-celled to multicellular organisms) but commoner culturally. Arthur (2009), analysing technological evolution, distinguishes degrees of 'saltation' – advances can range from minor tweaks (e.g. from single to compound steam engines) to major changes (e.g. the shift from steam to electric power). PIRA's development of mortar bombs is a perfect example of incremental innovation (Gill, 2017). Radical innovation was also evidenced, including the use of secondary devices (e.g. booby traps); bomb content (e.g. nails); and methods of delivery, initiation and detonation. One contact-initiation system, incorporated in an improvised anti-armour grenade, appears particularly creative. It debuted in 1987 and was an 'underarm-thrown grenade which deployed a small parachute to enable the charge to detonate at the desired angle and penetrate tank armour' (Oppenheimer, 2009:239). As another example, in 1981, PIRA debuted a bomb that incorporated remote-control initiation mechanisms, allowing PIRA to plan detonations well in advance. The peak of this innovation came several years later. In October 1984, PIRA targeted the British Executive, including Prime Minister Margaret Thatcher, during a Conservative Party conference in Brighton. Using a home-video recorder, a bomb was concealed within the hotel 24 days before detonation (Oppenheimer, 2009:239).

One particular kind of radical advance is based on the discovery/exploitation of *new physical phenomena* – whether using light in the development of vision among predators and prey, or radio waves in technological evolution. Although not in the same league, PIRA improved a radio-controlled device with the discovery of the 'white band' – an 'unimpeachable' radio signal immune from jamming (Oppenheimer, 2009:209). A contrasting instance of *recombination of existing phenomena and materials* relied on sheer technical ingenuity: an initiation system devised in 1983 'consisted of two copper plates insulated by greaseproof paper and was intended to be initiated by a sniper firing a shot through the plates' (Ryder, 2005:210).

## Selection

When an animal is foraging for food, establishing a territory or seeking a mate, it experiences various 'selection pressures' coming from the physical environment and the other organisms within it. These pressures together help determine the 'fitness landscape' to which the animal must *adapt* as an individual (through learning and/or development) or as a species (through genetic evolution) to flourish, not perish. On the human/cultural level, the fitness landscape itself comprises a succession of immediate opportunities and wider opportunity structures (Clarke and Newman, 2006) generating those opportunities; also various hazards to be avoided or coped with. A related concept is the niche – a career-level counterpart of opportunity – where adaptation is to a particular way of life, in a particular environment (applied to crime by Brantingham and Brantingham, 1991). Biologically, an animal must, for example, have good-enough hearing, armour or mobility to avoid or withstand its predators sufficiently often to survive for sufficiently long in order to breed; or it must catch and subdue its prey. Culturally, individuals and organisations must be able to make a living and/or achieve their strategic goals over sustained periods.

Selection in the technological/cultural domain of terrorism is about weapon designs and attack techniques working sufficiently well to be chosen for re-use and wider dissemination, versus failing and being abandoned.

The sheer *scarcity of resources* may be an important selection pressure. PIRA's dwindling stock of commercial explosives due to effective counter-terrorism efforts forced experimentation with homemade explosives, whose consequences are discussed below.

Products and techniques *compete* for adoption by the terrorist organisation and individual operatives. At an elementary level, the pressure for some innovation simply to work, i.e. having basic *functionality*, is considerable, whether it concerns a knee joint operating smoothly or a bomb initiator mechanism avoiding premature triggering. Working *better* is also important. Petroski (1992) noted that shortcomings of existing inventions may drive evolution of designs, citing everyday examples like zips. PIRA's early attack method of hijacking cars and planting bombs within them caused problems for synchronised warnings: using radio to initiate detonation conferred more control.

To generate fully functional phenotypes, and then to go on to confer advantage, both biological and cultural evolution must address *multiple fitness requirements* (Ekblom, 2012a, 2014). This necessitates the evolutionary 'learning' process (Watson and Szatmary, 2016), handling design contradictions, and trade-offs. Bomb-delivery systems were required, say, to be easy to control, destroying intended targets at the flick of a switch while simultaneously minimising civilian casualties or 'own goals'. But sometimes the trade-offs were too complex to resolve and the technique was abandoned. PIRA also introduced a method utilising infrared sensors like those used for remote operation of garage doors (Oppenheimer, 2009). While they allowed devices to be detonated from afar, they were temperamental and could be triggered by innocent passers-by.

Besides pressures of competition, devices and technique feature in *conflict* with the security services. An equivalent major selection pressure in the natural world is *predation*. Predators often track prey. The infrared sensors just described had the advantage in this respect of leaving no chemical forensic evidence behind for the police.

But who is the predator, and who is the prey, can vary. Felson (2006) describes possible interactions in three-party criminal relationships – victims, offenders, police – and notes that the latter's actions as top-predator may sometimes *benefit* the offenders' position as middle-predator, by preventing their runaway over-exploitation of the prey. How far this applies to the terrorist situation is unclear; techniques such as agent-based modelling, already used in crime (Birks, this volume) and often deriving from biological ecology, could help explore the possibilities and contexts where it might occur. We do know, however, that indiscriminate and fatal operations by British security services on the Catholic community led to spikes in PIRA activities, presumably due to increased popular support and the need to be seen to strike back (Gill, Horgan & Piazza, 2016; Asal et al., 2015).

There is a basic asymmetry of selection pressures between predators and prey, known (Dawkins and Krebs, 1979) as 'life versus dinner': if the predator succeeds, the prey dies; if the prey escapes, the predator only loses a meal. There are uncomfortable parallels here with PIRA's announcement immediately after the 1984 Brighton bombing: 'We only have to be lucky once, but you have to be lucky always …' (Gill et al., 2013).

## Fitness landscapes and their exploration

The 'fitness landscape' is a notional surface whose height reflects an organism's reproductive fitness relative to its customary habitat, and whose other spatial dimensions represent variation in any number of inherited traits.[2] The landscape is often rugged, with peaks and valleys representing respectively fitter and less fit combinations of traits – for example, a particular length of legs plus a particular musculature and particular acuity of vision may be fitter for the habitat than alternative variants. The cultural counterpart could be a combination of a particular weapon with a particular attack technique and particular communications technology when pitted against the customary enemy in the customary (say urban) habitat. In nature, evolutionary processes explore this landscape blindly, crawling over it nose-to-the-ground as variations are tried out, but wherever there is an upwards gradient, inexorably ascending.

Selection pressures thus tend to lead evolving generations of organisms up to the nearest, local, fitness peak they stumble upon. But here they often remain stuck, despite the existence of higher peaks across the valley floor. They are trapped by the fact that any change from local fitness is downhill in terms of performance, so moving out across the valley requires sustaining significant temporary disadvantage (perhaps relative to competitors) before previous fitness is regained and then exceeded. However, a route to higher performance may materialise when changes in the wider environment cause the local peak to collapse, evicting the organism from its formerly advantageous position.[3]

One illustration of this process in terrorism is where the security services reduced PIRA's access to explosives. Here, the effect was actually counterproductive for security, leading PIRA to adopt car bombs.

Car bombs possessed several advantages (Ryder, 2005): they could carry far more explosives; a car provided ample room for the firing mechanism; both car and device could be booby-trapped; planting a car bomb and keeping it undetected proved easier than with a bomb in a bag; and less manpower was needed for delivery. But this higher peak of fitness remained unexplored despite the clear tactical advantages – the leap in organisational and practical terms was too great.

The decision to innovate with these devices actually stemmed from the already mentioned diminution of PIRA's stock of commercial explosives due to British counter-terrorism action. PIRA was forced to experiment with heavier, bulkier f-based explosives, which necessitated a new delivery system. But that system, although arrived at by disruption of previously successful techniques, actually proved advantageous: it displaced PIRA from the previous peak and caused them to seek another one – which happened to be higher in fitness. Moreover, the above-mentioned benefits were amplified further by the fuel within the exploding vehicle; together these accidentally-encountered advantages helped account for the car bomb's significant proliferation in the 1970s (Ryder, 2005).

A subsequent instance of security service actions engendering a 'jump from the frying pan into the fire' centred on firebombs. The novel components of a new device included metal piping filled with commercial explosive attached to a container of petrol and a timer-power unit. Once detonated, the petrol boosted the incendiary effect. Intelligence experts believed that petrol was originally adopted in these devices, again purely to conserve commercial explosive stocks; but when PIRA realised the destructive effect of this IED, its use increased (Ryder, 2005:190).

Both fertiliser and incendiary changes, introduced initially as a means of coping with a new constraint but then leading to wider benefit, are reminiscent of what may have happened with the emergence of photosynthesis and its waste product, oxygen. Margulies and Sagan (1986) argue that aerobic respiration may have evolved initially as a way of blotting up this highly reactive poisonous pollutant, but it also happened to yield a major power boost. This may in turn have paved the way for active animal life, enabling predation and necessitating intelligence.

## Replication/transmission

Replication in nature is determined by three factors: *fidelity* (how accurately the previous generation of genes is copied), *fecundity* (how many offspring can be produced) and *longevity* (how long the replicating generation lives and remains fertile). In nature, replication is predominantly via vertical transmission, i.e. from one generation to another; horizontal transfer is rare (e.g. gene transfer in bacteria and imitation in higher animals).

In human culture, the reproducing entities are not genes, but, say, designs of weapon or attack technique, where the replication machinery is not DNA transcription and protein-synthesis mechanisms, but mental and social processes like perception, memory, imitation, recall and communication[4]; and perhaps generic manufacturing tools like soldering irons, lathes, chemistry labs and control software, plus the accompanying procedures of use. Besides the vertical transfer from experienced practitioners to novices, our imitative and linguistic abilities support an ever-increasing capacity for horizontal transmission, whether via face-to-face networks or, nowadays, the internet. And unlike in biological evolution, knowledge acquired in an individual's lifetime is inheritable by others.

With PIRA attack techniques, for obvious reasons fidelity in deployment of explosives was ensured by thorough training. This typically occurred within small groups, whose leader tended to have the requisite experience to convey to newer recruits. But the limited supply of expert teachers constrained the fecundity of such vertical replication mechanisms; horizontal mechanisms were also constrained, by considerations of security in face-to-face situations, where the cell structure of the organisation limited who knew whom.

In cultural replication, copying the *instructions* for making some artefact or undertaking some activity offers higher fidelity than copying the *end product* itself (Blackmore 1999). Hence manuals, e.g. for bomb-making and deployment, can boost longevity, fidelity and fecundity combined.

*Jurassic Park* apart, once a species is extinct, nature is stumped. But printed documents are durable and can even help to resuscitate any prior practice or product fallen into disuse. In cultural replication *reverse engineering* can revive defunct weapons and enable their reproduction. Here, the fitness function depends on having the capacity to develop an understanding (usually drawing on theory, if only of the elementary operation of gears and levers) of how some found product works, and is constructed.

The benefit of textual instructions may be constrained if *tacit* knowledge is also needed to replicate the weapon and/or its use – e.g. 'stir the mixture this way, till it starts to feel lumpy, thus'. But fidelity in this respect can nowadays be significantly boosted by YouTube-type video instructions, as with online guides to bomb-making (see Gill's, 2015, discussion of Ian Copeland's 1999 bombing campaign and Anders Breivik's 2011 bombing).

The internet further amplifies the benefits of textual and visual material alike: digital documents or video clips are less prone to copying error, and can last indefinitely; helpful forums offer advice from experienced practitioners. Fecundity, too, is amplified by the virtually zero cost of dissemination. Here, we seem to have switched from the cultural equivalent of what biologists call 'K strategy' – dedicating many resources to a few well-guarded and well-nourished offspring – to 'r strategy' – where, as with codfish, millions of eggs are churned out with very little cost per egg, very little prospect of any individual egg surviving, but a high chance that enough will do so to populate the next generation.

Besides the methods of replication such as the blueprints or procedural manuals just discussed, fidelity and fecundity can depend on what is replicated. The improvised nature of the weapons used by PIRA and other terrorists is relevant here.

In some circumstances, however, this logistical advantage was outweighed by unreliability. During the early 1970s, PIRA regularly used beer-can nail bombs because of their simplicity and cost-effectiveness (O'Doherty, 2008:59). However, their use proved dangerous to operators because they were manually-ignited and contained a short fuse. Upon detonation, the nails would explode in each direction. The fuse was also awkward to light because of nerves or strong winds. It was not always obvious that it *had* been lit, leaving the bomber seconds to decide whether to throw it or try lighting it again (and risk it detonating). Investment in greater sophistication and complexity of weapons – equivalent to the K strategy of replication above – was thus necessary in some circumstances.

The *persistence* of terrorist organisations like PIRA supports longevity in several ways. It allows experience to be accumulated and then transmitted to new generations of recruits over an extended period. Weaponry and techniques can be developed through sufficient iterations to remove snags and increase efficiency and effectiveness, promoting durability in the field. And these designs attain sufficient quality that other organisations choose to copy them. According to Asal et al. (2015), it was perhaps PIRA's expertise in IED technology that has had the longest impact upon terrorist activity globally. Arguably PIRA was responsible for the greatest innovations and the deepest expertise in the construction and deployment of IEDs by any non-state militant group. PIRA IED technology re-emerged in conflicts within Colombia, Spain (especially with mortar technology), Israel, Lebanon, Iraq, and Afghanistan.

Finally, there is *failure* to replicate. At one level, there may be just too few opportunities to use the techniques. One bombing in 1989 used a railway track to carry the pulse to initiate the concealed IED, based on a rare 'lucky' configuration. Or an entirely practical technique can fail for human-factor reasons (see Ekblom, 2012b for a wider discussion of 'involvement failure' in crime prevention). For example, condom-based timer devices (slowly eaten through by acid) worked well enough, but proved culturally unacceptable to Catholic terrorists, who would not want their parents to find the packets in their homes (O'Doherty, 2008:59). Conducive environments apart, broader reproductive factors are also important. However creative and technically successful they may be, particular attack techniques may fail in practice if the organisational/logistical ability for execution is lacking. In PIRA, an ingredient of their high level of performance was the successful combining of multiple levels of interacting actors as teams, leaders and organisations.

But at whatever level replication failure operates, it can be instructive. Knowledge of why particular weapons and techniques were tried but abandoned could shape preventive interventions, and turn incidental inhibitors into systematic blockers.

## Entities and their environments

### Adaptation

We have seen how variation, selection and replication of entities ranging from life forms, product designs, behaviours, and techniques, to wider social practices, together mediate the fundamental evolutionary algorithm, whether this is done genetically, psychologically or culturally. The outcome is that successive generations of these entities become better adapted to the existing fitness landscape and the hazards, opportunities and niches that shape it. Thus, they become better able to survive and replicate – or in the case of terrorist weapons and techniques, to be replicated by their human producers/users.

All three components of the algorithm are necessary for creativity to move from mere novelty generation towards innovation. If the innovation process is persistent, it moves the entity in a consistent direction, significant evolution occurs, and the entity becomes an ever-better match for its habitat. But tension between contradictory requirements (e.g. strength versus weight) means the solutions developed are usually optimal compromises rather than maximisations. Human culture can explore the fitness landscape in subtler and more systematic ways – for example, the invention of the internal combustion engine enabled the tank to simultaneously combine armour and mobility, whereas previously it had been one or the other. But the time and resources available to terrorists may be limited in the case of a clandestine organisation harried by the security services. Thus, in the absence of secure home territory and/or backing by states or large companies, what terrorists can do is limited by the need to *improvise* rather than thoroughly research, develop, produce and deploy entirely new weapons and tactics of substantial complexity and sophistication. But these hindrances may not always apply.

### Construction and affordance

Adaptation is not the whole story. Recent takes on evolution (e.g. Laland et al., 2015) have flagged the importance of the process of 'niche construction' – for example, where grazing-adapted mammals keep the landscape free of bushes, to their own benefit. Cultural-level examples of this process include places modified as concealed arms dumps, lookout posts, ambush sites or loopholes for shooting. All of these niche construction efforts facilitate the use of evolved weapons and attack techniques, and of course they evolve themselves. Wider *social* niche construction processes could include 'climate setting' (Ekblom, 2011) where terrorists exploit, and actively manage, acceptance of the use of particular weapons and techniques among a supportive population. A related evolutionary perspective – the affordance landscape – has recently been developed by Walsh (e.g. 2015) as a contrast to the conventional fitness-landscape point of view. Here, the evolving organism, seen as an active agent, seeks out what is useful and useable in its environment. The resonance with weapon improvisation is clear, and Walsh's thinking can be applied to build further on the (non-evolutionary) treatments of terrorism and affordance in the volume by Taylor and Currie (2012).

## In the face of change

The abstraction that is the fitness landscape is no more static than its geological counterpart. It undergoes the equivalent of mountain building, valley formation and occasional landslips due to changes in the environmental, economic, technological, political and social background, operating over various temporal and geographical scales. Some of the changes experienced by adaptive entities are entirely exogenous, such as when an earthquake diverts a river, the market suddenly raises the price of copper or a new religious movement emerges. In terms of crime, see reviews of the wider effects of technological change by Ekblom (2017b in press) and Felson and Eckert (2015). Other changes result from the actions of third parties, e.g. when a rival gang seizes territory, or police priorities change; and still others from an entity's own actions, e.g. overgrazing, whether of pastureland or of houses to burgle. Whatever the case, as the Provisionals and their opponents discovered, over some appropriate timescale, fitness is therefore always precarious, and … provisional.

How do biological or cultural entities cope with these changes? Before adaptability comes *resilience*. Resilience at its most elementary is about simply tolerating the change (e.g. a terrorist organisation accepting more arrests by the security services while continuing as before). In more advanced instances, resilience includes deploying alternative responses from one's existing repertoire. An example is where the growth of British Army intelligence in Northern Ireland raised the difficulty for PIRA to plant big car bombs. Road checks and security cordons limited opportunities, so PIRA strategists turned to smaller, easily concealed incendiary devices (Ryder, 2006).

True dynamic adaptability comes with innovation in, say, anatomy, behaviour or technology, which tracks the changes in the fitness landscape. Genetic evolution is the slowest adaptive process, taking generations; learning can pick up changes during the lifetime of individuals or groups; deliberate design-based problem-solving can be rapid; and cultural-level change is variable – adoption of mobile phones being lightning-fast but gender-equality rather slower.

In the rest of this section on change we first address factors that accelerate adaptation, and then cover the issue of co-evolution, which often serves as an accelerant in its own right.

## Accelerants of adaptation

Various *accelerants* facilitate adaptation and reduce the waste and hazards of failure.

A feature of more advanced biological organisms is the capacity to generate *plausible variety* – novel body forms that have a fair a priori chance of conferring advantage (or at least of being neutral) rather than being a totally blind guess (Kirschner and Gerhardt, 2005). A mutation for longer leg bones, say, is accompanied by matching developmental growth of muscles, nerves and blood vessels rather than these being entirely out of step (which would not get the animal very far). This coordination is mediated by complex systems for control of anatomical development through regulatory genes, and leads, for example, to the astonishing range of plausible, workable body-shapes expressed by vertebrates all based on variants of the same underlying plan. This is an instance of the wider concept of the 'evolution of evolvability' (Dawkins, 2003), i.e. the invention of means to make evolution faster, more efficient and of wider scope. In cultural evolution terms, Ekblom (2014) flags its significance in the design of crime-prevention measures which are theoretically and practically plausible rather than a complete shot in the dark. The body of theory and practice knowledge, and the skill in applying this in generating, testing and improving new weapons and techniques, amounts to *innovative capacity* (Ekblom and Pease 2013). This is to be distinguished from *operational capacity*, which depends merely on deployment of existing weapons/techniques.

The same holds for design by terrorists, but here the underlying knowledge covers the physics and chemistry of weapons, camouflage, how to mislead opponents, etc. (variation);

development and testing procedures (selection); and, as seen, how to supply apprenticeship experience, handbooks and YouTube instructional videos (replication).

One of the hallmarks of PIRA's ability to survive and adapt was its substantial technical and innovative acumen in IED development. Arguably PIRA produced the greatest innovations and the deepest expertise in construction and deployment of IEDs by any non-state militant group. Underlying this was the propensity of the PIRA engineers to come from professions whose skills directly applied to the craft of bomb-making; and the Engineering Department's coordination of research and development in armaments. Often the seniors in the Engineering Department included many skilled technicians (see Gill, 2017).

## Flying leaps

As said, fitness peaks can trap evolving organisms when there is no way to change which does not involve first going downhill. But humans can sometimes leap from one fitness peak to a higher one *without* traversing the valley of degraded operational performance. This releases significant constraints on evolution, which moves from purely local maximising of benefit, to a more global reach (i.e. from the best of all local possibilities to, in the extreme, the best ever, anywhere). The variation and selection process in human technology can involve taking evolving tools and weapons *out* of the real-world fitness landscape and harsh, immediate selection pressures, and *into* protected and even imaginary landscapes of backs-of-envelopes, workshops and field trials. Here, exploration and invention can be undertaken with significantly reduced risk from failure, where psychological pressures of, say, risk of arrest or accident are lower too, and where what is good about some innovation can be salvaged even though the product as a whole did not succeed. Popper's (1972) maxim is particularly apt here: while in the real world, almost every exploratory action puts animals' survival on the line, in the course of imagination and trials we humans allow ideas to die in our stead. Dennett's (1995) concept of the 'tower of generate and test' extends this idea by documenting a range of progressively smarter ways of adapting and learning – Pavlovian, Skinnerian, Popperian and Gregorian – where we invent tools which themselves make us smarter. This was very much the case with the PIRA Engineering Department. Many of its senior members were skilled technicians, who undertook much co-ordinated 'backroom' research and development in armaments, a factor fostering operational success (Horgan and Taylor, 1997).

## Co-evolutionary arms races

When entities are evolving side-by-side, pursuing a mix of competing, conflicting and collaborative goals, and each comprises a significant part of the other's environment, we enter the domain of *complex adaptive systems* (e.g. see www.cas-group.net). These are particularly tricky for policymakers to influence (Chapman, 2004; Kurz and Snowden, 2003): any perturbation they attempt to introduce usually has unpredictable and complex effects as one entity adjusts to exogenous changes or to those brought about by the others, like the clampdown on commercial explosives described above. When complex adaptive systems generate a progression of changes leading in a consistent direction we can talk about co-evolutionary arms races.

Arms races arise in the gene-level world mainly between predators and prey (e.g. ever-harder shells vs. ever-stronger teeth), and pathogens and hosts (e.g. fungal infection vs. inherited resistance genes). They also emerge between humans and nature (e.g. pesticides vs. pests) and between different groups of humans (e.g. in military domains such as radar vs. stealth). Ekblom reviews criminal (Ekblom, 1997, 1999) and terrorist arms races (Ekblom 2016), as do many of the chapters in Sagarin and Taylor (2006). Move, counter-move and counter-counter-move can unfold. In the everyday crime world, the aforementioned co-evolution of the safe and safe breaking techniques (Shover, 1996) is a good example.

In our case study of terrorism, the security services jammed PIRA's radio-controlled IEDs, leading PIRA to refine the radio-control mechanism to incorporate encoding and decoding (Oppenheimer, 2009). And PIRA turned from car bombs to van bombs to restrict the line-of-sight of explosive ordnance disposal (EOD) teams (Ryder, 2005).

In a longer sequence, standard PIRA IEDs were incrementally accompanied by secondary, anti-handling devices. The 'Castlerobin' was a wooden box containing both anti-opening and anti-lifting micro-switches, introduced in 1971. If it was moved, tilted, or opened, it would detonate. It killed the first EOD operative to attempt to defuse it. A second EOD death through this IED illustrated more malevolent creativity in which the designers anticipated, and manipulated, the perceptions and scripts of the EOD team. By burning the fuse on the IED, PIRA made it look inoperable. However, anti-handling mechanisms detonated the IED as the EOD officers moved the device by wire. The natural world is replete with examples of different kinds of *deceit* on the part of predators and prey alike (Stevens, 2016), the glowing lure of the angler fish being just one instance. Research by behavioural ecologists into when and how these techniques work, and how countermeasures can evolve, may not yield many specific ideas we can copy (Ekblom, 1999), although animal camouflage tricks were consciously adopted during both world wars (Stevens, 2016). But the principles of advantage, disadvantage and contextual fitness factors can be abstracted and applied by security services.

A noteworthy arms-race process exclusive to human culture involves, again, *reverse engineering.* Either side can use this, whether in copying a captured weapon, or in understanding how it works in order to overcome it. After five of PIRA's 'Castlerobins' were captured, unexploded, at a bomb-making factory, EOD operatives quickly learned how to disarm them.

The military concern with 'capture-proofing' advanced weapons illustrates yet another strategy – *controlling information about offensive/defensive tactics* – which does have counterparts in biological evolution (Vermeij, 2008). Such information can be used against opponents, much as HIV exploits what it has 'learned' about the response of the immune system to gain a foothold in the human host. Equivalently, PIRA scouts started noticing British soldiers collecting unlit nail bombs. Consequently, PIRA members began leaving seemingly unlit ones in locations where the soldiers would likely find them. The 'safe' nail bombs were accompanied by mercury tilt switches, however, so that moving the device detonated them (Gurney, 1993).

Humans have evolved to be *unpredictable* predators par excellence. Tooby and DeVore (1987) argue that the evolution of human intelligence allows us to mount *evolutionary 'surprise attacks'* which escalate the arms race against prey, such that the latter cannot keep up through their own biologically evolving counter-adaptations which are more limited in scope and slower to emerge. When we try this against our human enemies, of course, the tactical advantage of surprise is still a potent one, but the enemy may be on the alert, may have anticipated some such move, and may have surprises of their own in store.

Central to surprise is radical innovation, demonstrated by the PIRA despite their reliance on improvisation. We have already seen the novel use of the video recorder timer in the Brighton bombing of 1984, enabling its planting weeks in advance. Another example was in 1971, when PIRA placed an IED in a sewer, to float downstream under an Army post. The effort failed as it detonated beneath an empty bar (Ryder, 2005); but today's GPS capability in smartphones could overcome navigational inaccuracy; and various autonomous robot crawlers could remove the dependence on water currents and subterranean channels. Indeed, aerial drones are now a risk.

A related arms-race issue is that of *silver bullets*. Although they can only be used once before rapidly deployed protective measures obliterate the opportunity, single-shot attacks can be game-changing, as 9/11 showed. A PIRA example was a delivery system used once only, in 1992, involving a stolen excavator and laundry van. PIRA volunteers removed the van's tyres to enable it to run along a railway track on its rims. The excavator lifted the van onto the tracks. The van was loaded with 1,000lb of explosives. The van was put into gear and sent along the track, driverless. Its open backdoors allowed for the command wire to unreel alongside the railway tracks. As it got close to an Army Barracks, it was detonated (Gill, 2017). Here, the strategic issue for the terrorists and security services alike is to ensure their innovative capacity can continue to generate a stream of surprises, with both tactical advantage and strategic shock value. But one drawback of continual surprise is the limited scope for consistent improvement, and in some cases the risk of failure – of either the device/technique not working, or blowing up one's own personnel, including valuable experts.

Ecological circumstances may influence whether ad-hoc exploration and limited clashes of offensive and defensive technologies and techniques become prolonged evolution in a consistent direction. In some cases, PIRA did move into more systematic research and development (see Oppenheimer, 2009).

## So what?

This chapter has focused on the technological innovation of weaponry and attack techniques in PIRA, but the processes abstracted with the aid of evolutionary thinking apply to other terrorism-waged conflicts and to the struggle with organised crime (Kenney, 2007).

We argue that adopting an evolutionary perspective on terrorism and counter-terrorism helps us understand and exploit past history, beneficially influence present risks, and prepare for future challenges. The *co*-evolutionary perspective confers additional benefits in highlighting the simultaneous consideration of attack and defence, move and counter-move, and the symmetries and asymmetries between the opposing parties in a complex adaptive system. More generally, it enables us to detach ourselves from immediate battles and view the conflict strategically.

Evolutionary thinking does not just bring in genetic or cultural processes, significant though these are: it facilitates interdisciplinary links to other fields where the evolutionary algorithm is considered to apply. These include the immune system, learning, and thinking mechanisms (e.g. Plotkin, 1997; Watson and Szatmary, 2016). And divining the *differences* between the different evolutionary domains (cf. Jablonka and Lamb, 2014) helps to clarify concepts, surface assumptions, and see what is distinctive about cultural/technological evolution. In turn, this shows us how to hinder adaptation in terrorists while boosting it for the security side, without jeopardising wider societal values. In crime science in particular, the evolutionary perspective helps set opportunity-based approaches (Gill et al., 2018) in a context of longer-term processes of adaptation, and wider ecological structures such as niches.

We focus next on three aspects of counter-terrorism policy and practice which seem particularly informed by the evolutionary perspective – the need for an anticipatory stance, how to handle co-evolution, and the importance of design.

## The guessing game

The substantial lag in time to detect a potential threat, decide what to do and implement it in the field means that careful *anticipation* is better than reaction alone.

It is virtually impossible to predict the precise onset of specific innovations within terrorist organisations (the same is true with technological innovations in general). But it may be possible to predict *evolutionary trends* in various technological fields. The TRIZ approach, described in Ekblom (2012a) and https://triz-journal.com/triz-what-is-triz, identifies such trends. An example is evolution from fixed mechanical links between components, to hinged links, to infinitely variable links, like bicycle chains, to electromagnetic fields. Knowing such trends can help us anticipate where the next development in some product, process or system might be expected to come from, whether introduced by legitimate engineers or terrorist ones. We can also undertake more specific *technology road-mapping* (identifying the sequence of innovations needed for a particular new technology to become feasible). On the last, we can understand what upcoming innovations could be misused by terrorists (Ekblom 2005) and take advance action to make this difficult. This equates to the way disease control experts now assess how many mutations some disease might need to undergo to gain the capacity for human-to-human transmission (e.g. www.sciencedaily.com/releases/2016/04/160404090554.htm).

Undertaking *future-proofing* is also worthwhile. For example, we can make security measures easily upgradeable rather than locked into a system that gets left behind by malevolent or incidental changes in technology or tactics (what use was the Maginot Line in the face of new, highly mobile, Wehrmacht armour that simply drove round the end?).

The adaptive stance also requires us to *build and maintain our repertoire of knowledge* in terms of generic principles, theories and practices of counter-terrorism that together with on-the-ground intelligence, enable us to design, develop, test and deploy our own plausible innovative variety of offensive and defensive measures. Conceptual frameworks of the kind cited in this chapter can help here, much as the rich web of regulatory genes generates plausible variety in nature.

## The arms race

The adoption of a co-evolutionary perspective on terrorism suggests that we should both view and do things differently. In viewing, we get to see the conflict from a standpoint that rises above the month-to-month slog and counter-slog of the arms race, which could enable us to think more widely about responses. In so doing, if we want to avoid losing whole campaigns despite winning individual battles, we must continually out-innovate adaptive/innovative offenders against a background of changing technology and other contextual factors that favour first one, then the other, side. We must deliberately accelerate our adaptation. Ekblom (1997, 2016, 2017b) lists approaches which could be adopted to '*gear up against crime*'. Strategic examples include encouraging plausible variety as already discussed; and abstracting generic *principles of inventiveness* (e.g. the 40 inventive principles and 39 contradiction principles of the TRIZ approach – Ekblom, 2012a) which could specifically be applied to crime, terrorism, and perhaps the military.

We should also hinder the adaptation of the terrorist side. Understanding of biological counterparts may suggest how to disrupt research and development processes by confining terrorists to exploration/simple improvisation rather than allowing them to progress to R&D proper.

It may also be possible, given the correct information, to predict a terrorist organisation's *capacity for innovation* and attempt to downgrade that accordingly. For example, organisational-level innovation such as changing from a strictly hierarchical structure with a clear command and control to a more linear one has the potential to increase the levels of tactical innovation that may follow (Gill et al., 2013). If certain conditions are known to favour the persistence or re-emergence of hierarchy, other things being equal it may be possible for the security services (and/or civil society more generally) to act in ways that support this trend. For example, this could involve deliberate (albeit ethically sound) efforts to sow distrust within terrorist networks.

To finish on a more generic point, constantly changing ecological conditions have tended to favour generalists and prevent specialists from evolving (think rats versus highly desert-adapted rodents). However, this risks the entities evolving higher-level adaptive capabilities: arguably this happened with human ancestors who gained intelligence under the very changeable climate of the African Rift Valley (Shultz and Maslin, 2013). A terrorist organisation that is always being challenged in new ways may either succumb or – on the principle of that which doesn't kill you makes you stronger – become more agile and adaptive. More tactically speaking, too, it is debatable which is better for the security services (and the society they serve) – facing a whole series of diverse improvisations or a steadily more advanced, but knowable, technological progression.

## Design

Design is needed when we face challenging, competing or conflicting requirements. With terrorism, these are obvious: balancing security against the need for economy and efficiency (tactically combating terrorism, and maintaining an adaptive stance, are costly); the need to protect the full range of wider societal values such as democratic principles, privacy and inclusivity; the need to boost enterprise and economic growth; and the requirement to reduce our carbon footprint. Governments are constrained by these considerations; terrorists are often free to set many of them aside although they have constraints of their own (relating to resources, the risk of capture/defeat, the need to maintain a supportive constituency or to out-compete rivals). Design enables us to live with this asymmetry – for example, by finding ways that degrade terrorist innovation *without* similarly degrading that of legitimate businesses; or at a more tactical level, of scanning passengers' bodies at airport security gates *without* intrusion on privacy (millimetre-wave scanners are designed to display schematic body images rather than intimate details of individual passengers).

But design goes beyond ingenuity in addressing known problems, to *reframing* the problems themselves. Dorst (2015) gives many examples of this process, including turning a yearly drunken riot in Sydney's Kings Cross area into a civilised festival; and reframing the requirement to design an anti-terrorist litter bin for a railway operator, into one that also reduces false alarms – thankfully a much more common, but very disruptive, problem (see also Lulham et al., 2012). Jumping out of the direct ding-dong of arms races is a major such reframe, perhaps the biggest, but which may not always be possible, is to arrive at some mutually beneficial political settlement between the conflicting parties.

# Conclusion

Terrorist attacks will never go away, and no adaptations to them can be perfect, nor predictions reliable. The 'War on Terror' can never be won – protective action and pursuit of perpetrators can only keep the problem under control until political resolutions become possible. It is an instance of the 'Red Queen's Game' (van Valen, 1973, from Lewis Carroll's *Alice Through the Looking Glass*). In that game you must keep running merely to remain in the same place. (Schneier, 2012 offers a detailed exploration of its security implications.) This is true both as a general principle and for the technological examples we have presented in the case of PIRA weaponry and techniques.

But we cease to run the arms race at our peril. Studying evolution, and more specifically co-evolution, gives us knowledge of generic solutions that have been tried and tested in the very long run, over a wide range of 'universal' ecological problems faced by natural organisms of all kinds; and recapitulated over a far shorter timescale by humans in conflict with 'nature' and each other.

An evolutionary approach that draws in crime science, engineering science and design together with evaluation of effectiveness and systematic accumulation of process knowledge (know-how), can provide a fresh perspective and a richer understanding of terrorist attacks, supporting attempts to control them that are more strategic and change-oriented than have customarily been the case. This is especially so when we add in sophisticated knowledge management. In this manner, we can hopefully out-innovate adaptive terrorists while preserving our cherished values and serving the widest range of societal priorities in a proportionate way.

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## Notes

[1] A useful critique of the original meme concept is in Jablonka and Lamb, 2014. This accords less weight to the copying element and more to the social and ecological context in which the copying occurs.

[2] A good account of the fitness-landscape concept, with some interesting graphics, is at https://en.wikipedia.org/wiki/Fitness_landscape.

[3] For a schematic representation of this process, see https://en.wikipedia.org/wiki/Fitness_landscape and scroll down to the gif diagrams of static and dynamic fitness landscapes.

[4] Although the biological replication layers are still necessary to support the cultural ones.