**System Design Feasibility Study for**

# The Autonomous Peace Officer (APO)

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**Abstract**:

*System design feasibility study for an agile, responsive, sentient, anthropomorphic machine, an Autonomous Peace Officer (APO) for Peace Operations in military and civil environments.*

## 1 The Issues

The anthropomorphic, autonomous police robot has moved out of the realms of fiction – Robocop – and into the real world – in the form of R.Bot 001, patrolling the streets of Perm in the Urals[1] So far, it is rather basic, and was put out of action on the first day of duty by rain getting into the electronics – but the idea is out there, and police robots will be with us in the future.

Army robots may come first. While a police robot might be envisaged operating with full autonomy, an army robot is more likely in the short term to be operating under orders and relatively close control…And then there are military UAVs which could also, in the future, take on a more autonomous role.

So, is it possible to establish a coherent design for such potentially complex, autonomous entities, with their potential to do great damage as well as good?

Autonomous machines are often portrayed in the media as slow, unresponsive, unaware, unreliable, and unable to interact effectively with people, etc., i.e.; all the things that a real Peace Officer should *not* be.

Is it possible to create an APO that would be effective at maintaining 'the Queen's Peace' while at the same time being socially acceptable to the people—the weak, the vulnerable and the villains alike not to mention the civil liberties lobby?

### 1.1 The Challenge

1. To conceive and design an APO: capable and effective in social, antisocial and disordered situations; able to assess 'people, places and things[2],' characteristics, behaviours and threats; able to interact effectively with people—suspects and victims alike.
2. An APO should be able to perform the full range of Peace Officer duties: patrol, using intelligence to seek disorder in 'people, places and things;' deter disorderly behaviour by visible policing; identify and, if necessary, combat, pursue and apprehend suspects and miscreants in complex urban environments; support and protect the weak and vulnerable from abuse and oppression; apply proportionate force, ('tit-for-tat…') etc.
3. From the design study, to consider if an APO is currently feasible, and to identify areas of research needed to make it so…
4. From the design exercise to consider whether an APO is a realistic and sensible proposition…

### 1.2 Stakeholder Prejudice…

The start-point, as ever, is the problem space. A useful way to investigate the problem space is to consider how future stakeholders might view an APO. People have long had a love affair with autonomous, anthropomorphic machines, going back in history to *Talos, the man of bronze* in Greek myth, and in medieval times to suits of armour, which could be made to move around in human-like fashion, using strings and pulleys.

[1] See: http://rawstory.com/news/afp/Robocop_takes_to_Russian_streets_06262007.html

[2] Police way of categorizing situational information

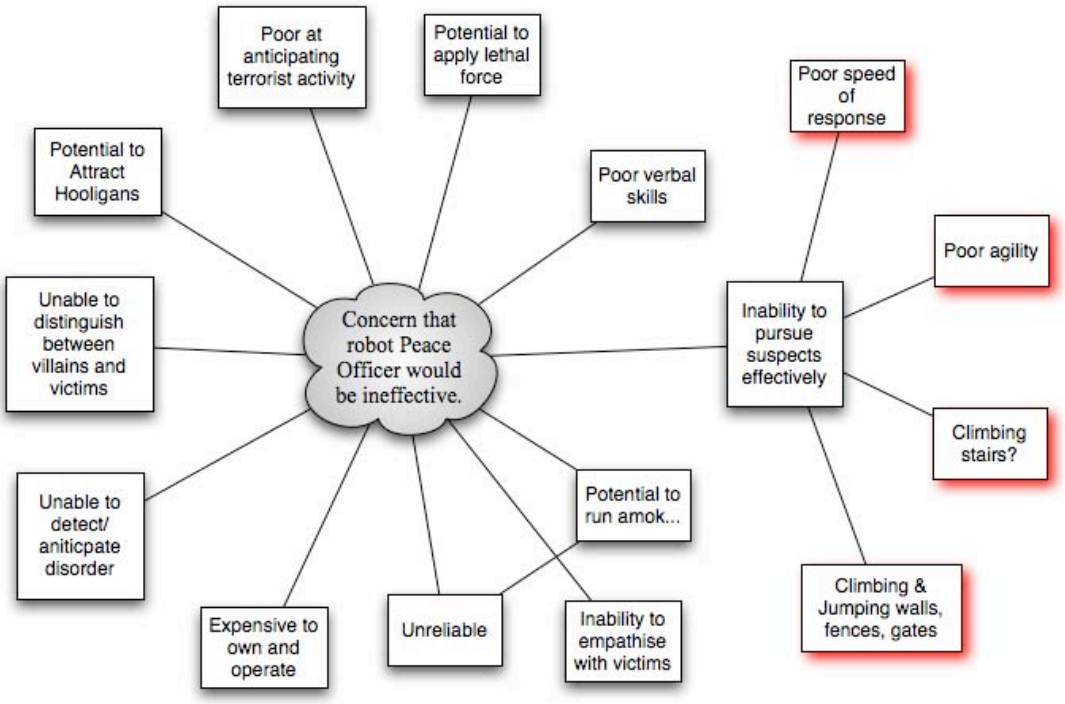


**Figure 1. Stakeholder Prejudice w.r.t. Autonomous Peace Officers.** Stakeholders would include the public, victims, villains, the police service, and even terrorists.

Japanese researchers (the Toyota Motor Company - TMC), are actively creating working robotic 'partners' to work with people in domestic, nursing and medical care, manufacturing and short-distance personal transport: TMC are careful to make their wheel-mounted, humanoid tour-guide robot, TPR-Robina, which can interact with visitors using verbal communications and gestures, only 4ft tall, to be 'non-threatening.[3]' This feature highlights concerns about machines being perceived as threatening to humans…

So, the idea of introducing an autonomous Peace Officer, endowed with authority, the power to intervene in disputes and to enforce the law, will bring antipathetic notions to the fore.

Figure 1 represents anticipated stakeholder prejudice, where the stakeholders in question are those who might have something to gain, or particularly something to *lose*, from the introduction of APOs. Stakeholders would include politicians, the general public, local government, police, victims and villains, and terrorists…

[3] Engineering Technology, September 2007,Vol. 2. No.9

### 1.3 Problem Themes

To explore the problem space, each of these contributions to the concern about APO ineffectiveness is explored, and the results brought together and interrelated. Each concern suggests that systems implicit in the APO's design and creation might 'not be up to the job.' Annex A shows some of the exploratory work carried out in this context, using Purposeful Behaviour Modelling.

Bringing together implicit systems identified in the Annex points to major problem themes; these themes focus the design effort since, unless the problems can be resolved, stakeholders' worst fears would be realized.

The problem themes are shown at Figure 2; there are four major problem themes, plus one yet to be identified:

1. Situation assessment
2. Behaviour cognition
3. Operations Management
4. Safety control, and…
5. The 'physiology' of the APO. This latter arises from the first four, all of

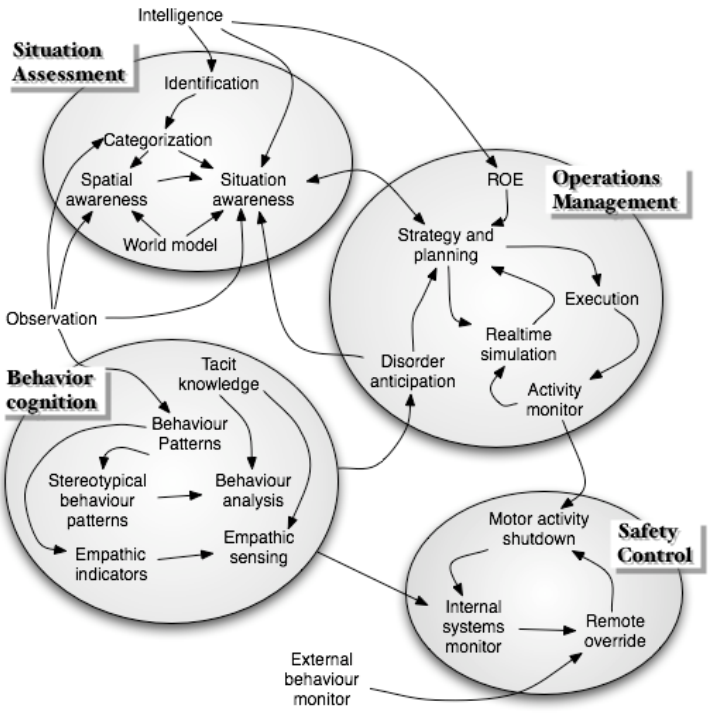


**Figure 2. APO Design - Problem Themes.** See Annex A for source.

which emphasize the need to operate decisively – which cannot be fully realized unless the intent of the APO is matched by an equally responsive physical response – however achieved technologically.

### *1.3.1 Situation Assessment*

The APO will need to perceive, recognize and assess situations, where a situation may range from a crying child in the path of a speeding vehicle to a group of armed terrorists intent on blowing up as many innocent civilians as possible.

The APO will have sensors to perceive, reference models to categorize, 3-D world models and tacit knowledge to recognize what is being perceived, and the ability in general to be situationally aware.

These capabilities will operate very rapidly, such that situation assessment can lead to appropriate action in very short order. For an experienced human peace officer, the expected time frame might be a few seconds at most, with instinctive reaction occurring in about 20ms: the APO must at least match that, since the human element (e.g., villains and terrorists) in the situation will invariably behave dynamically.

### *1.3.2 Behaviour Cognition*

The APO will deal largely with people, and it will be essential for the APO to interoperate effectively with people. It will need to recognize human behaviour, much as current police officers do. For instance, where an individual is observed waving his, or her, arms (uncontrolled limb movement in police terms) there will be a suspicion of psychological agitation presaging aggression – unless, of course, the subject is a TV presenter, most of whom wave their arms like demented windmills.

### *1.3.3 Operations Management*

The APO will be required to conduct complex operations, which may be adapted in real time as situations develop, e.g., pursue a dodging suspect through a suburban housing estate.

Potential operations will require rapid planning and simulation of proposed actions to see of they are likely to be effective in context.

Surprisingly, this is what we humans do all the time, although we may not always be aware of it.

We can see it at work in ourselves, for example, when driving along a single lane road and catching up a slower vehicle. We may look ahead and see another vehicle coming the other way, in the distance. We have the ability to judge whether or not we have sufficient room to overtake safely before the oncoming vehicle arrives. How? It seems that we perform some kind of faster-than-real-time simulation, which, if successful, gives us a mental 'GO.'

Some of us, of course, are better at this than others – experience clearly helps. The APO will need to match our inherent capability.

### *1.3.4 Safety Control*

The exploration at Annex A suggests that there should be some foolproof way of remotely closing down APO motor activity in the event of it's running amok. This would create vulnerability – should the shutdown mechanism become known, the bad guys could use it. Some other approach than remote shutdown may be advantageous.

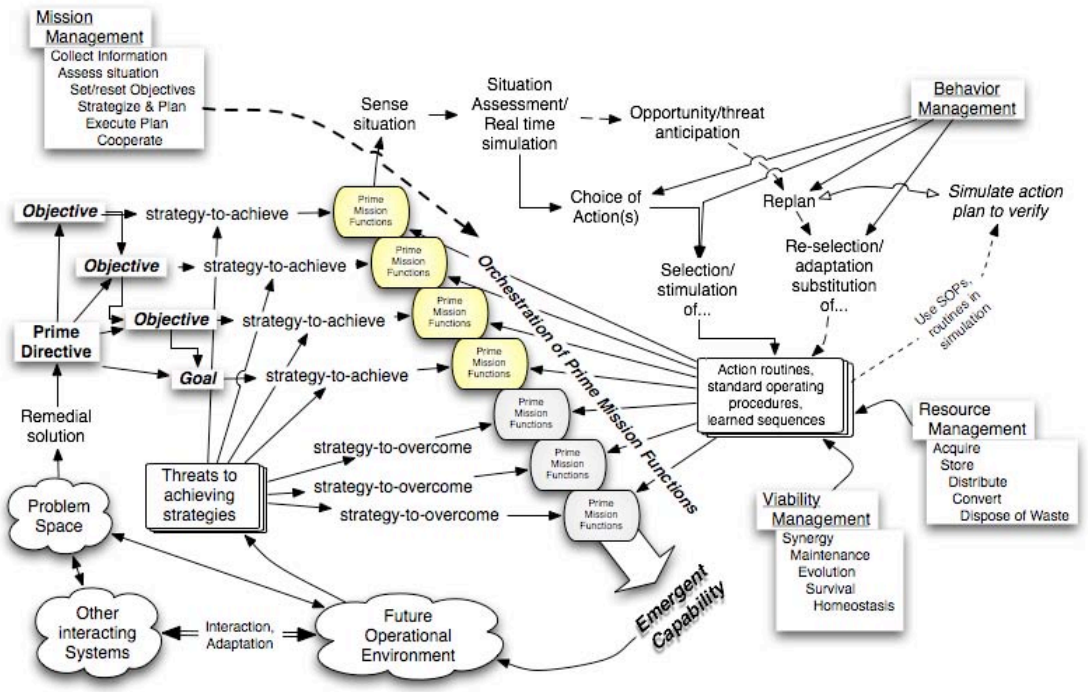


**Figure 3. The System Design Concept.** The objective is to create 'Primary Mission Functions," that delineate the APO's capabilities, and to develop these by identifying and orchestrating a set of action routines, operating procedures and learned routines. The APO needs the ability to sense situations (top), assess them in real time, choose appropriate actions, simulate them to test their potential, and stimulate them in sequences that create each PMF. As the figure shows, there is a circular process resulting in closure, as the activated PMFs create emergent properties, capabilities and behaviours in the Future Operational Environment (bottom) which resolve the various problems and issues within the Problem Space.

## 2 Systems Engineering: Synthesizing Emergence

At this point, the complexity of the design task is beginning to show itself. The APO will fit in the class of systems dubbed IDA – Information Decision Action Systems – which, as the title implies, take in information, make decisions and then act upon them; all in real, or near real, time.

Typical members of this class of systems are: emergency services; air traffic management; military command and control; individual humans; and many more. In each of these examples, the intelligence required to make rapid decisions is vested in humans as operators, decision makers, executives, etc. The APO, however, will be required to function intelligently without human involvement – a deeply serious challenge to systems engineering.

IDA systems exhibit emergent properties, capabilities and behaviours: these necessarily include responsiveness, decisiveness, integrity, and many more.

Emergent properties, capabilities and behaviours[4] derive from the *interactions* between the parts of a system, which must therefore complement each other, cooperate and coordinate their actions and interactions.

The essence of systems engineering, then, can be seen as:

> *The selection of complementary parts; configuring their interrelationships; and, the 'orchestration' of their many functions and interactions to synthesize requisite emergent properties, capabilities and behaviours of the unified whole.*

For an APO, emergent properties, capabilities and behaviours would include: anticipation; decisiveness; speed of response; discretion; integrity; sensitivity; resilience; robustness; effectiveness at maintaining order…

[4] Properties of the whole that are not exclusively attributable to any of the parts.

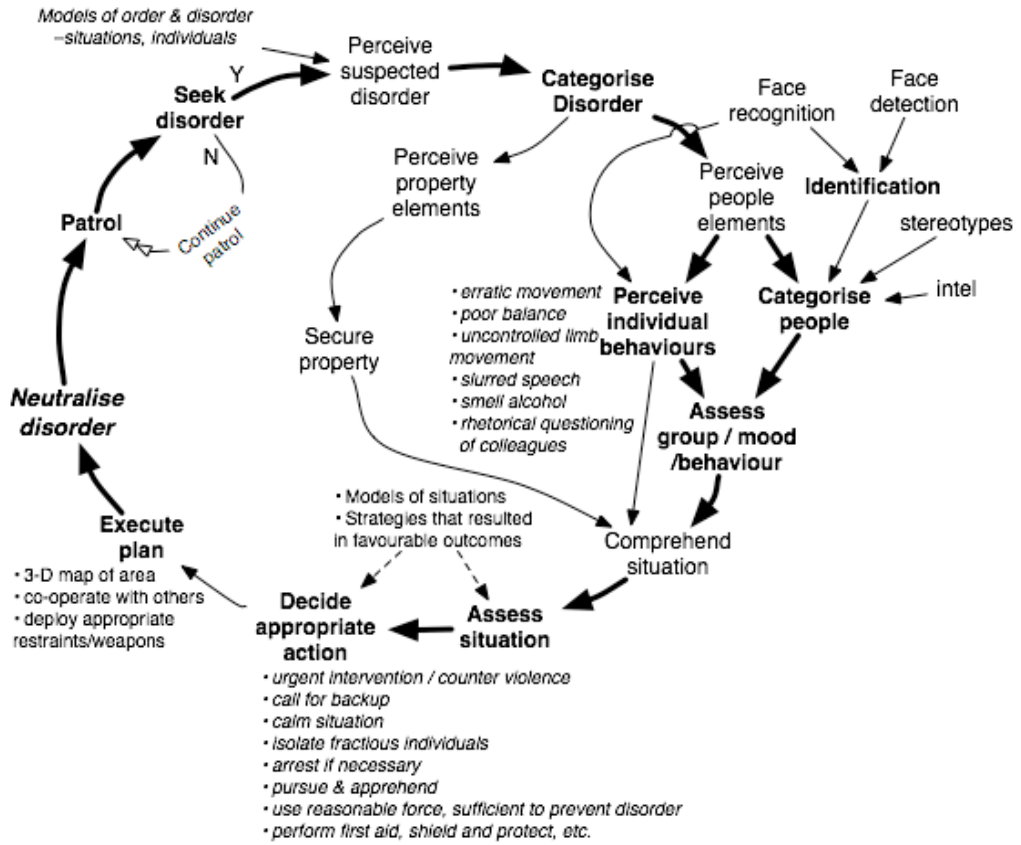


**Figure 4. APO Concept of Operations (CONOPS)**

Creating an APO is perhaps the severest fully autonomous, general-purpose social robot… c.f. Data from Star Trek

### 2.1 System Design Concept

Figure 3 shows the system design concept, which is manifested in a systems methodology [1], encompassing both soft and hard aspects of open system design in context.

#### *2.1.1 Primary Mission Functions (PMFs)*

PMFs for an APO will be largely what would be expected for a human Peace Officer:

- Patrol
- Receive and transmit intelligence, situation reports, video, data, voice-communications, etc.
- Deter imminent unlawful behaviour - visible policing
- Detect actual or impending disorder (unrest, aggressive behaviour, civil disorder, crime, terrorist activity, etc.
- Detect, locate, categorize, identify (potential) perpetrators
- Warn, advise, negotiate
- Pursue, intercept and apprehend
- Restrain, using reasonable force (suggesting non-lethal weapons)
- Shield and protect injured and vulnerable
- Co-operate with others in all of the above

Note that each of the PMFs includes both 'cerebral' activities in its selection and management, and physical motor and sensor actions. This paper is concerned principally with the 'cerebral' aspects, since these will largely decide responsiveness and energy requirements for the physical features.

## 3 CONOPS

All of the above PMFs would be deployed at some time in the Concept of Operations – see

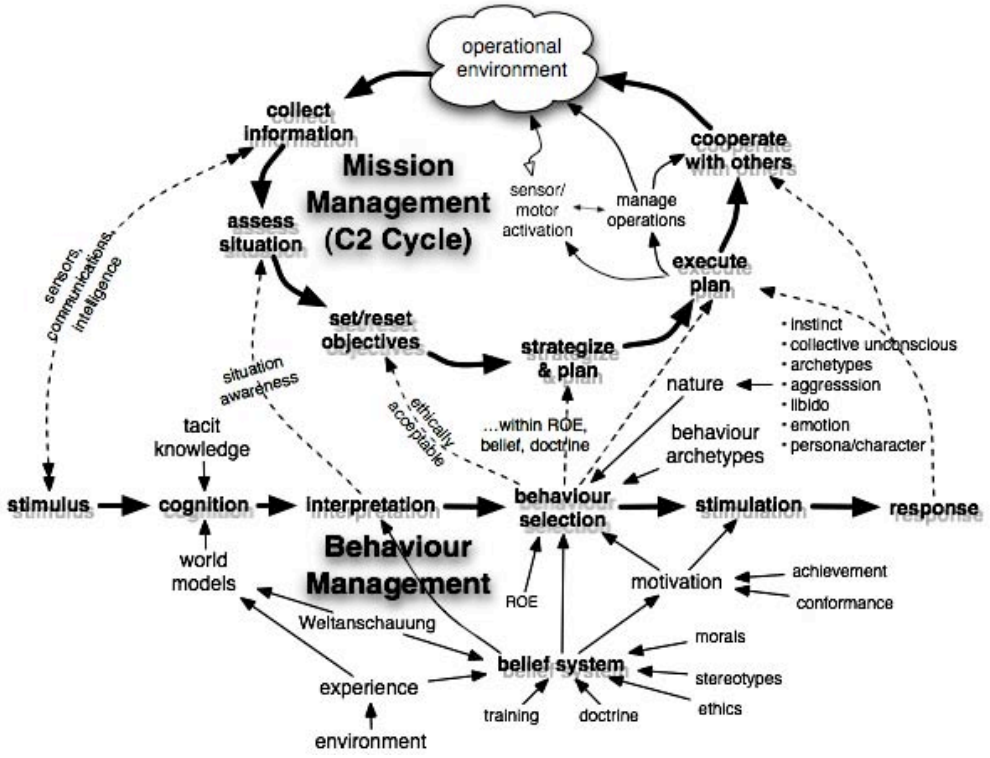


**Figure 5. Part of the Generic Reference Model**, which will serve as a design 'framework' on which to 'hang' the APO functional design and architecture. The upper 'circle' forms the well known command and control (C2) cycle widely employed in Mission Management. The lower section goes from stimulus (left) to response (right), showing how behaviour is invoked as response to stimulus. The two sections are connected, indicating ways in which behaviour influences the C2 cycle. The GRM shows logical structures and relationships, but need not be configured in the best way for particular functional architectures.

Figure 4. The term 'neutralise disorder' in the figure is non-specific, since the nature of the disorder determines the APO's choice of action, weapons, etc.

## 4 The Generic Reference Model…

The Generic Reference Model (GRM) [2] purports to describe the internals of any system, where a system has Form, may perform Functions and may exhibit Behaviours. As an Information-Decision-Action (IDA) system, the APO invokes all three aspects of the GRM: Being, Doing and Thinking; or, Form, Function and Behaviour. The GRM serves as a framework upon which to 'hang' the APO design.

Figure 5 shows only part of the GRM: Mission Management (which, together with Resource Management and Viability Management, comprise Function Management); and, Behaviour Management. The Form section is not shown explicitly; once functional and behavioural aspects are determined, form aspects will follow ('form follows function.')

In the figure, the Mission Management, or C2, cycle is a continuous loop of assessing and responding to a continuously changing situation. Situations change as the 'players' in the situation act, and as the System-of-Interest (SOI) – the APO in this instance – also acts. Mission Management may, therefore, be managing several missions at once, each in various stages of progression and adaptation.

- The Behaviour Management model is founded in Jungian philosophy: which raises issues such as, would an APO:
- 'behave;' if so, why and how?
- need/have a Belief System?
- have a 'nature,' with all that implies, including instincts and archetypal behaviours?

- have moral scruples, and apply ethical principles? If so, whose?

# 5 APO Design Considerations

## 5.1 APO Behaviour Management

An APO has to interact with people. Successful interaction requires that the APO exhibit human-like behaviour; present a persona appropriate to situation (avuncular, disciplinarian, friend, etc.); protect, support and empathise with victims; be 'tit-for-tat'-aggressive towards miscreants, etc.

'Guiding' such behaviours (in humans) are instincts and behavioural archetypes (Jung). For an APO, two such archetypes seem appropriate:

- The shepherd protecting his flock against marauding wolves
- Society's chivalrous champion, knight of the Round Table
    - … Honour, truth, justice, defence of the weak and women, etc.

Such archetypes constrain behavioural response, permitting only analogous patterns of behaviour in contemporary situations

For the APO, a knight-shepherd archetype would seem appropriate, such that whatever actions might be 'rationally' chosen by the APO in given, or unexpected, actions would always be subject to the consideration: 'would a knight-shepherd do this?' If he/she would not, then the 'rational choice' would be inhibited.

How such archetypal behavioural supervision would be implemented may be problematic, but it provides a cogent alternative to remote shutdown, with its attendant vulnerability.

Classically, behaviour is response to stimulus - sentient response may differ with situation, and with repeated stimulus. In Figure 5, a stimulus is recognized and interpreted:

- cognition involves categorizing the stimulus according to world model, tacit knowledge and belief - i.e., what the stimulus is expected to be…
- world models are representations of the world in which the APO will operate, which allow reasoning - including *Weltanschauung*… 'world view'
- tacit knowledge is low-level knowledge of how things are/behave. The amount of tacit knowledge can be vast, rivalling that of the human genome…
    - grass is green, things fall downwards, ice is cold, etc.

Multiple stimuli are recognized, correlated to create an impression or 'picture' of a situation - an interpretation, based partly in belief – becomes 'situation awareness.'

The interpretation of stimuli may invoke a corresponding behavioural response: there will be a range of archetypal behaviours…

- some knee-jerk (i.e., fast, reactive; potentially life saving)
- others more considered and constrained by archetypes (shepherd, knight, etc.)
    - … based on training, experience, rules of engagement (ROE,) doctrine, etc.
    - … so, more likely to engender successful and acceptable outcomes

Behaviour influences the command and control cycle at a number of points:

- The situation to be assessed is based partly on belief
- The objectives to be set/reset, acceptable strategies, etc., will be mediated by belief, ethics, morality, ROE, behavioural archetypes, etc.
- The execution of a plan will be influenced by motivation, by acceptable levels of aggression, etc.

Overall, the rational, logical, objective $C^2$ cycle is properly subject to belief, behavioural archetype, etc., etc. This will be necessary for an APO, both to make its behaviour sensibly human-compatible, and to circumscribe its range of missions/actions when encountering new situations: its behaviour must be 'humane.'

# 6 APO Functional & Behavioural Design

## 6.1 3-D Cognitive Awareness

The APO will operate in a 3-D space and require 3-D cognitive awareness:

- A built-in 3-D inertial mapping system presents a current view that APO should be able to 'see' all around.

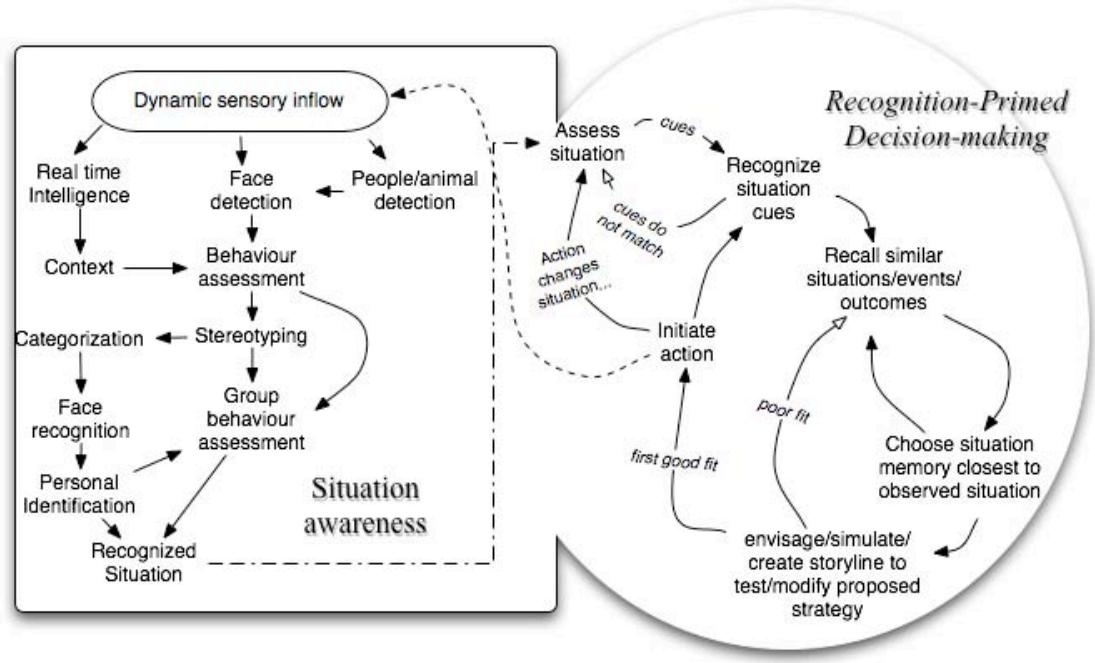


**Figure 6. Situation awareness and Recognition-Primed Decision-Making**

- SatNav is unreliable inside buildings, underground car parks, tunnels, etc.

- APO visual / I-R sensors correlate visual pictures with 3-D map using optical matching techniques
- Optic flow analysis picks out moving features, people, and locates them in 3-D map space
- Face detection / recognition / analysis + stereotyping + intelligence categorizes people—may identify them and their emotional state

- Behaviour analysis and empathic sensing indicate current state and imminent intent of people

Together, these establish 3-D cognitive aware-

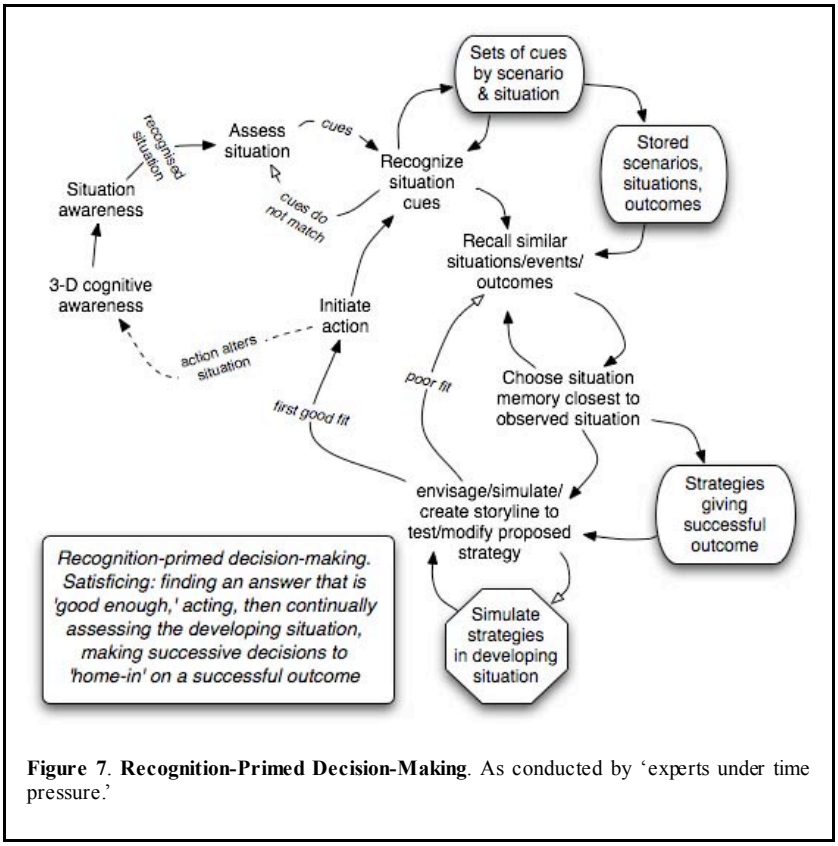


**Figure 7**. **Recognition-Primed Decision-Making**. As conducted by 'experts under time pressure.'

ness, leading to situation awareness.

### 6.2 Strategies, Planning and Decision-Making

Figure 6 illustrates the development of Situation Awareness and the formulation of fast decisions following the Recognition-Primed Decision-Making paradigm [3].

At left is an Intent Structure, showing how various pieces of information may be brought together to create a dynamic picture, or representation, of an ever-changing situation. Note the use of stereotypes; people use stereotypes to categorise other people; while some decry this as 'inappropriate,' it is likely to be innate and instinctive behaviour in humans and, in the past, to have enhanced survival. Put simply, if persons present themselves as villains or thugs, they should not be surprised if a Peace Officer considers them to be villains or thugs until proven otherwise. The Peace Officer has little sensible choice…

At right in Figure 6 is a conceptual approach to making decisions based upon a developing situation.

### 6.3 APO Decision-making

Figure 7 shows RPD – Recognition-Primed Decision-making – in more detail. Klein [3] established that this was the manner in which experts of long standing made decisions, even although they were unaware of the fact, considering instead that they had developed an 'instinct.'

RPD is 'satisficing'—finding a solution that is 'good enough,' as opposed to one in which all the 'pros' and 'cons' have been weighed to establish an overall best solution. In practice this 'best solution' process may take far too long, and evidence shows that novices who use this approach may still get the wrong answer.

RPD, on the other hand, makes a snap decision on the immediately available evidence, and then monitors the situation to see if it is developing as first supposed. If not, successive decisions will be made in the light of developing information, until the decision-maker homes in on the right answer.

RPD is fast, flexible and adaptable. It depends, however, on the decision-maker having expert knowledge and being able to simulate proposed actions to test their potential suitability. In the case of the APO, some expert knowledge would be provided, and the APO would go through an extensive learning program.

### 6.4 Execution and Mission Control

In an Information-Decision-Action (IDA) system Command (or executive) is fully occupied continually reviewing evolving situations, planning and strategising, so, to prevent overload, APO Mission Control is necessarily handed-off to subordinate 'mission controllers'.

We are personally familiar with this: a person, when taking part in some action, does not consciously 'operate' arms and legs, eyes and ears. Instead, these are controlled subliminally, while 'higher brain functions' observe, assess, predict, formulate strategies, mentally-simulate, plan, etc.

### 6.5 Executing the Plan: Control 'handoff'

In Figure 8, the command 'loop' continuously assesses the evolving situation, strategising, formulating 'short-term' plans and mission-

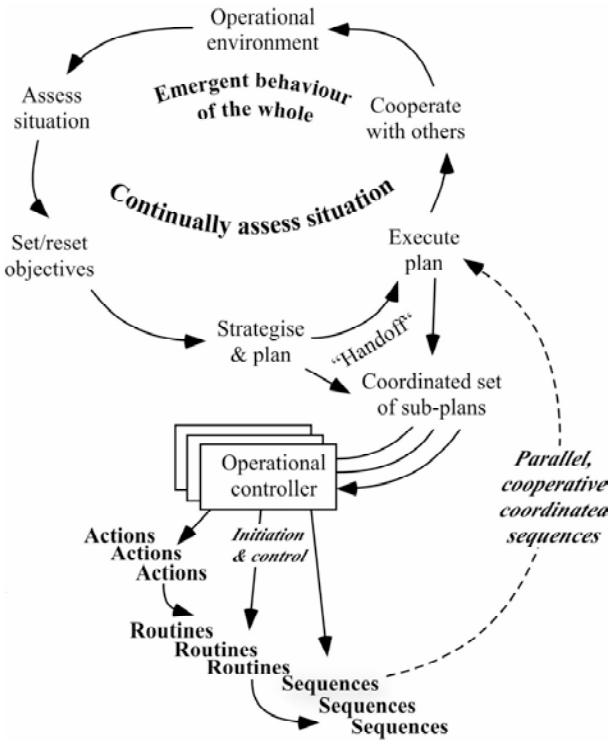


**Figure 8. Control Handoff**. The command loop is continuously busy as situations change. Control of the *execution* of strategies and plans is 'handed-off' to operational controllers, who manage the execution of coordinated sets of sub-plans, each of which will call for actions, routines comprised of actions, and sequences, comprised of routines. This, then, is the 'orchestration' of actions, functions and interactions which results in emergent properties, capabilities and behaviours…

elements.

Command delegates (hands-off) control of plan execution to avoid 'process overload:'

- Plans are delegated to cooperative operational controllers…
- …Which 'orchestrate' actions, routines, sequences, resulting in the manifestation of Primary Mission Functions (PMFs)
- These 'orchestrated' interactions between PMFs create emergent capabilities
- …through complementary, cooperative, coordinated sequences

But, how might this be achieved in an APO? After all, this orchestration is at the root of emergence…

### 6.6 Mirror Neurons…Mirrors in the Mind

Recent primate research [4] shows that:

1 Sequences of motor actions are triggered by firing patterns of neurons, which serve as templates. Neuron 'strings,' or neuronal chains, correspond to action sequences

2 …That the same neuron chains fire when *observing* another undertaking the same action, or experiencing the same emotion - hence 'mirror neurons'—mirroring observed acts.

3 Different neuron strings fire according to the *intent* of the action in context (sic)

So, for example: observing someone picking up a teacup fires a different neuron string if the intent is to drink tea, or if the intent is to clear the cup away for washing.

This important finding confounds earlier suppositions that intent was deduced rationally after

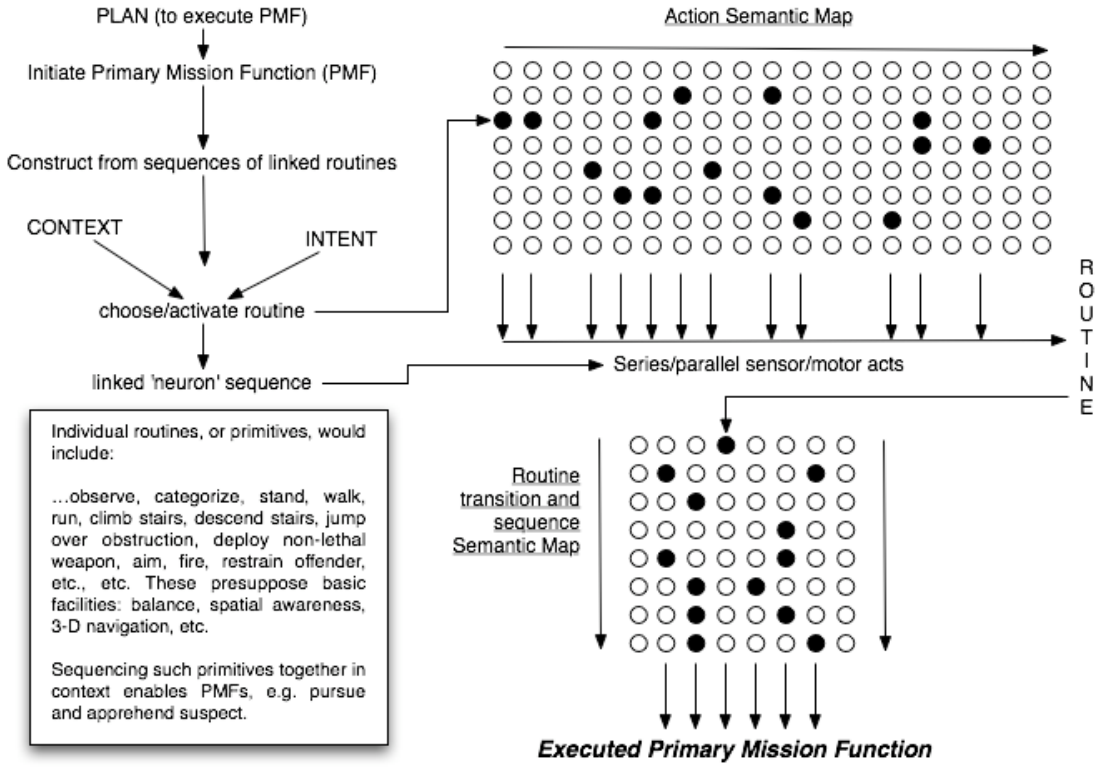


**Figure 9. Orchestrating Principal Mission Functions (PMFs)**. A plan to execute a PMF is formulated, top left. Each PMF is a complex, comprised of linked actions, routines, transitions and sequences of routines. A routine is comprised of several actions, according to context and intent. The corresponding string of acts that make up a routine is stored on an 'action semantic map,' capable of storing thousands of such strings. 'Firing' a particular string activates a particular routine. Routines may be activated in sequence and in parallel using a 'routine transition and sequence semantic map.' The whole process executes actions, routines and sequences amounting to the chosen PMF. Using this approach, several PMFs may be activated and may operate at the same time. Moreover, the plan may be adapted 'on the fly' as situations change, calling for different routines and sequences, perhaps even a different goal.

observing actions. Instead, intent is 'perceived' from the *nature* of the *object* acted upon; the *context*; and, from *memory* of what had happened previously.

"The motor system is organized in neuronal chains, each of which encodes the specific intention of the act …a strict link thus appears to exist between the motor organization of intentional actions and the capacity to understand the intentions of others."

Parallel observations showed that we appreciate emotions of others in much the same way. This suggests a basis for empathy…

All of which strongly suggest how we might be able to organize and orchestrate both motor and sensor capabilities within the APO.

And even that it may be possible for an APO to observe and ***empathize*** with offenders and victims…and to anticipate their ***behaviour***.

### 6.7 Orchestrating PMFs from Routines

Rizzolati's research suggests how we might organize the orchestration of actions, routines and sequences – see Figure 9.

The figure shows how a plan is formulated that invokes a Primary Mission Function (e.g. pursue and detain suspect).

Each PMF is made up of routines (e.g., stand, transition to running, run toward suspect, run to avoid obstacles, run toward suspect, continuously gauge distance to suspect, launch 'sticky net' when in range, stop running, restrain suspect, check suspect's health, etc.)

Each routine is comprised of a number of discrete actions. Stand from sitting might comprise: tilt trunk forward around hips; push off seat with hands; support body weight on legs as centre of gravity moves forward; straighten legs to standing; retain balance throughout. If the intent is to transition to running from sitting, then a different routine would be invoked, one in which the body was tipped forward of vertical as the weight moved forward, so that a faster, smoother transition to running occurred.

As Figure 9 shows, semantic maps may be developed to store actions in sets according to intent, routines as coordinated sets of actions, and sequences as coordinated sets of routines such that the PMF is activated, managed and achieved swiftly and flexibly: provided, always, that the mechanisation of physical features such as skeleton, motor/sensor networking, 'musculature,' 'tendons,' and power delivery are adequate.

### 6.8 Empathic Sensing of Intent

Using the concept of mirror neurons, it may be

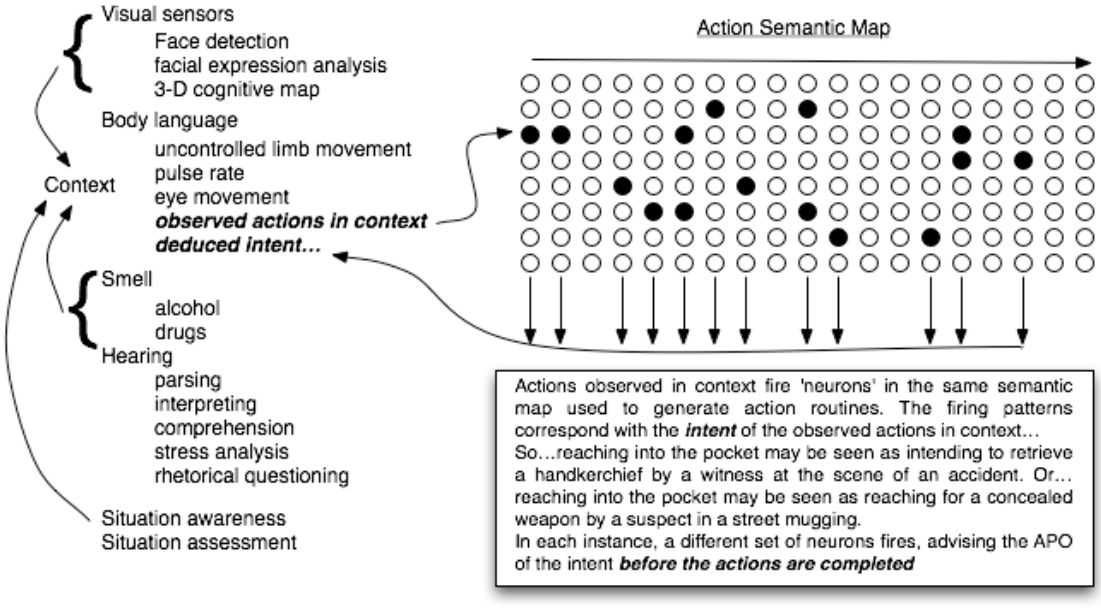


**Figure 10. Empathic Sensing?** At left are some of the sensors and sensor analytical techniques, which might be employed. Observing actions in context may enable an APO to deduce the intent of those actions before their completion…

possible for the APO to observe a series of actions in context, and to deduce their intent prior to outcome – see Figure 10. Ideally, this capability would use the same semantic map as for motor/sensor orchestration.

### 6.9 Evolving Semantic Maps

It may not be feasible to anticipate every routine, every sequence of every mission. Instead, prototype APOs may learn basic routines in the first place by trial and error, much as a young child: e.g. stand up from lying face down…

The APO must be able to deal with the unexpected, using built in routines and processes, but piecing them together by 'trial and error' to create new sequences within the archetypal behaviour patterns

Where such trials are successful, these form new sequence paths on the Semantic Maps, i.e., learning from experience…The knight-shepherd archetype will inhibits selection of unacceptable strategies, ROE, sequences, etc., so providing oversight and an essential safeguard.

## 7 Physical Aspects

### 7.1 'Physiology'

The physical design of the APO manifests the functional design, else:

- Unresponsive, inadequate speed, energy wastage…
    - E.g., need equivalent of 'elastic' tendons to store energy during locomotion
- Continuous (analogue?) computing for greatest speed - numerical accuracy may not be 'the name of the game:'
    - Qualitative rather than numerical…
    - e.g., Suspect A is more agitated than suspect B
    - Situation X is 'closer to' Reference scenario B than Reference Scenario Q…
- Physical subsystems may act/interact nonlinearly for greater energy density
- Sensor/motor coordination suggests non-linear behaviour

Research into prosthesis suggests touch-sensitive hands, fingers and feet will be both feasible and important for many applications…which also suggests an analogous 'neurological system' will be needed, allied to the motor/sensor systems.

### 7.2 Balance

An anthropomorphic APO must be able to balance, which will be particularly challenging for such a potentially agile and dynamic device. Balancing is a continuing sequence of routines, each differing according to context and intent

- balance while seated refers to torso and head
- balance while standing is related to the local perpendicular, head, torso, legs, feet…
    - vertical is detected visually, and using built-in inertial sensor, sensory feedback…
- transitioning to walking involves tipping the body forward
- …and to running and climbing e.g., stairs, more so
- running around an obstruction requires complex lateral tipping
- …while swimming is different again
- …as is bending over with the head below the waist

Contextual balancing routines will employ the same sensor and motor elements as many PMFs…so, sensor/motor coordination and actuation will accommodate overlapping 'neuron firings' such as might occur when balancing and jumping, or balancing and pursuing, at the same time. This raises design issues:

- Do overlapping firings result in a faster, or more powerful motor actions, or both?
- If so, do overlaps combine algebraically, logarithmically, or whatever?
- The 'physiological' design is yet to be determined, and will prove as challenging as the functional architecture design

### 7.3 Survivability

APO survivability can be considered under the four usual headings: avoidance of detection; self-defence; damage tolerance; and, damage repair

For covert operations:

- Visual/IR video with 3-D map matching; sonic and ultrasonic sensing, analysis and video-cueing; smell, inc. explosives detection; e.s.m. for suspect emissions…

For self-defence:

- Kevlar exterior, thixotropic underlayers, 'springy' cartilage-like skeleton, exoskeleton surrounding sensitive components - also formed from non-rigid materials…
- Self defence weapons: electric shock generation; 'sleeping gas' extrusion; hilux flash gun; stun grenades; smoke grenades.

Damage tolerance

- Distributed, multiply-redundant sensor, motor & 'neurological' systems
- Self-healing biomaterials …

### 7.4 Communications

Integral communications, relative navigation and identification (CNI) system—tied to built in 3-D inertial navigation system

Open 2-way communications with India (intelligence) Officer in HQ:

- Voice, data, video, maps, etc.
- Intelligence, Rules of Engagement, identification…

Open network communications with other peace officers

- Human and APO

The patrolling APO serves as mobile real-time intelligence generator, broadcasting 3-D video of current situation, using 'eyes' as cameras…

The APO can serve as communications centre:

- Citizens can communicate with remote human officers–video conferencing

### 7.5 Sensors & Weapons to fulfil PMFs

In addition to video and communications…

- Inertial 3-D navigation, updated by satellite navigation when available
- Low power range-only radar to detect movement, esp. behind
- Aural sensors for situation awareness, warnings, interviews and interrogation, etc.
- Directional aural cueing for camera 'eyes' in APO head.
- Lateral electrostatic and air pressure sensors to warn of close approach
- Nasal sensors for alcohol, drugs and illness.
- Touch & feel…plus 'hand'–'eye' coordination
- Strong hands, arms and legs to apply straightforward physical restraint without damage
    - Trained in unarmed combat?
- 'Sticky net,' to be fired at fleeing suspect
- Dart gun to temporarily stun/paralyze dangerous suspect
- Vehicle-disabling device…such as a short-range electromagnetic pulse (SREMP) device?

## 8 Functional Structure…

Figure 11 summarises progress towards a full functional design by 'hanging' the functional design so far on the reference model framework. While most aspects have been addressed, noticeably the 'nature' of the APO has not been fully addressed (other than archetypes and persona – which may require that the APO be able to display facial expressions – particularly important when dealing with children.)

### 8.1 Viability Functions

Of course, there is much more to the design than Mission Management and Behaviour management, crucial though they may be. Continuing viability of the operational APO will be vital, too, and may be considered using the acronym *S*-MESH ('es-mesh'):

***S*** — Synergy between the many parts to orchestrate requisite emergent properties, capabilities and behaviours

- Cooperation, coordination, complementation between parts to create dynamic, unified whole will require, *inter alia*, fast, non-blocking intra-networks

**M** — Maintenance: detection, location, and repair/replacement of defective/faulty parts.

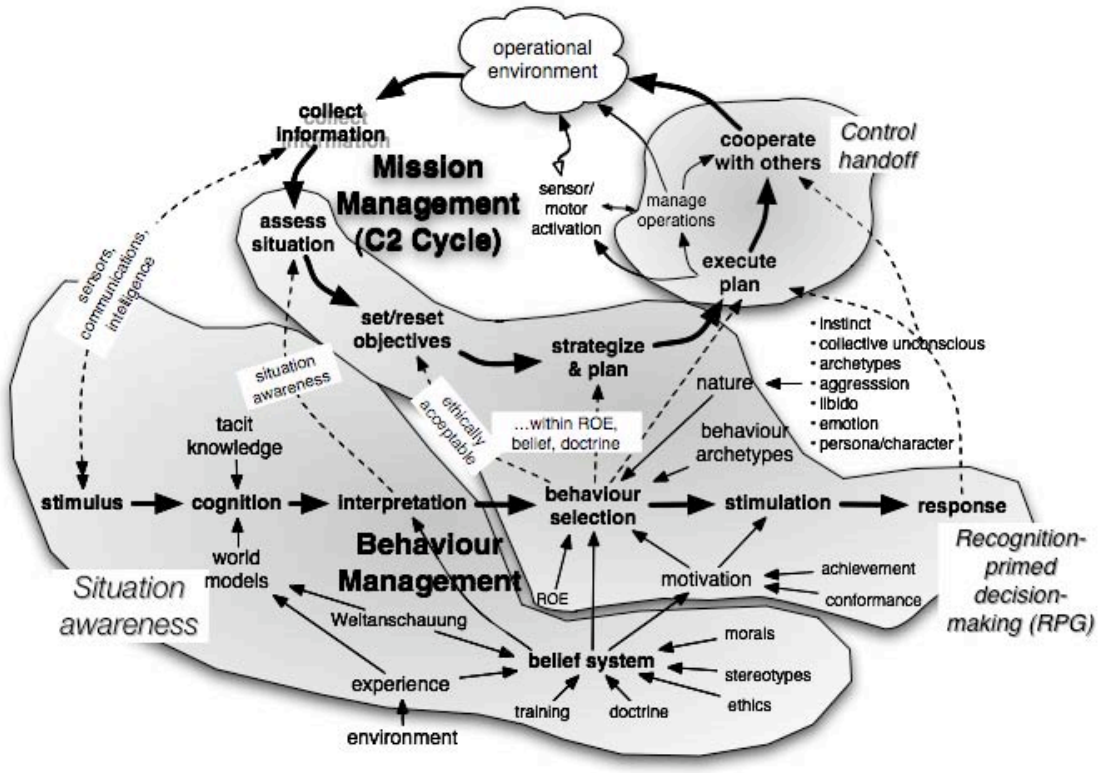


**Figure 11. Developing Functional Architecture**. Figure 5 showed the design reference framework. The figure above shows how three major design subsystems map on to that framework: Situation awareness; Recognition-primed decision-making; and Control handoff – effectively, the management of operations, through sensor/motor activation. In effect, the design study is generating a number of interacting 'cerebral' cortices…

- Implies either redundancy, self-repair and or self-healing…

**E** — Evolution: adaptation to changing environment

- Since the APO will function and operate in a continually evolving environment, the ability to evolve will need to be built-in.
- There are attendant risks, however, that the machine may evolve to be something less than desirable – hence the need for the inviolable knight-shepherd archetype to maintain behavioural integrity

**S** — Survivability: avoidance of detection; self-defence; damage tolerance; damage repair

**H** — Homeostasis: dynamic open system stability; inflow/outflow balance of material, energy and information

- Energy and power systems have yet to be designed – they will depend on the 'physiological' design, which will require power densities similar to, but perhaps in excess of, adult humans.
- There is an implication that non-linear systems interactions will be needed to achieve the necessary energy and power characteristics…

*All of the above are major design challenges for an APO*: continuing viability is fundamental to effective operations.

## 9 Is it feasible?

In parts…many of the various parts that go to make up the functional whole are becoming separately understood, but engineering parts to operate in near real time will be challenging.

For example, facial detection can be swift, but facial recognition/identification much less so, as presently developed. Similarly, reading 'body language' is an innate human skill, but will need careful development, training and proving for an APO.

Orchestrating parts to interoperate and adapt effectively in complex, socially-disordered, even life-threatening situations will be challenging

and high-risk, e.g. essential 'hand-eye' coordination for restraining suspects, deploying weapons, self-defence, etc

Orchestration implies the need for extensive semantic maps, with thousands of stored sensor/motor routines:

- Will these be pre-programmed, or learned?
    - If learned, how will the learning be accomplished, and how long will it take?
    - Will learned routines be transferable between APOs, to reduce training time and cost?
- There will also be a need for many stored scenarios, situations, strategies and outcomes, together with the need to access and compare these in faster-than-real time.

All of which suggests that the design process is essentially conceiving a ***set of linked artificial 'cerebral' cortices…***

Designing and engineering the 'physiology' to complement the 'cerebral' capabilities of situation awareness, recognition-primed decision-making and control hand-off, will be challenging:

- fast sensor/motor cortex requires corresponding fast physiology.
- fast 'muscles,' elastic 'tendons,' jointed-but-taut 'skeleton'
    - should these be hydraulic, pneumatic, electromechanical, biomechanical, a combination, or something else altogether?

Balance will be an issue: present anthropomorphic balance keeping at least one 'foot' on the ground, e.g. when climbing stairs. Honda's Asimo Humanoid Robot can run on the level and in circles, and can climb and descend stairs – but not on the run – yet[5]. Running up and down stairs two-at-a-time is much more challenging (for humans, too.)

Developing robot physiology to match human capabilities will be a significant challenge - but is surely feasible in the mid-term.

[5] See http://www.youtube.com/watch?v=cfaAiujrX_Y

Energy and power may not be an issue where APOs have facilities to 'recharge on the GO'

## 10 Is it a good idea?

The complexity and potential cost of designing, creating, testing and *proving* the first APO would be significant: the human Peace Officer is highly adaptable and affordable and will remain ahead of any APO for decades ahead.

However, APOs could operate continuously in hostile environments, could save many lives, while volume production would reduce per-unit costs

APOs may be culturally unacceptable in the real world - although that might change. With exposure, they could be seen as innately unbiased, culturally neutral, implicitly fair, etc.

*Designing* an APO is a worthy exercise, and is highly recommended for SE education and training courses…it brings together systems thinking, soft systems, hard systems, designing-in emergent properties, capabilities and behaviours, systems integration, etc.

- Shows how to 'design-in' emergent properties, capabilities and behaviours
- Gives great insight into all IDA system designs:
    - emergency services,
    - NCO/Network Enabled Capabilities (NEC),
    - Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR),
    - etc., etc.

## 11 References


[1] Hitchins, D. K. (2007) Systems Engineering: A 21st Century Systems Methodology, John Wiley, Chichester, UK

[2] Hitchins, D.K. (2003) Advanced Systems Thinking, Engineering and Management, Artech House, Boston MA

[3] Klein, G.A. (1989) Recognition-Primed Decisions, Advances in Man-Machine Research, 5, JAI Press

[4] Rizzolati, G., Fogassi, L., Gallese, V. '*Mirrors in the Mind,*' Scientific American Vol. 295 No.5, Nov. 2006

**Annex A**

# Exploring the Problem Space— Purposeful Behaviour Modelling

The figures show how different symptoms from Figure 1 may be used to probe into the implicit systems structure of the problem: it is presumed that these implicit systems may be dysfunctional, either separately or acting and interacting together. See The Rigorous Soft Method [1].

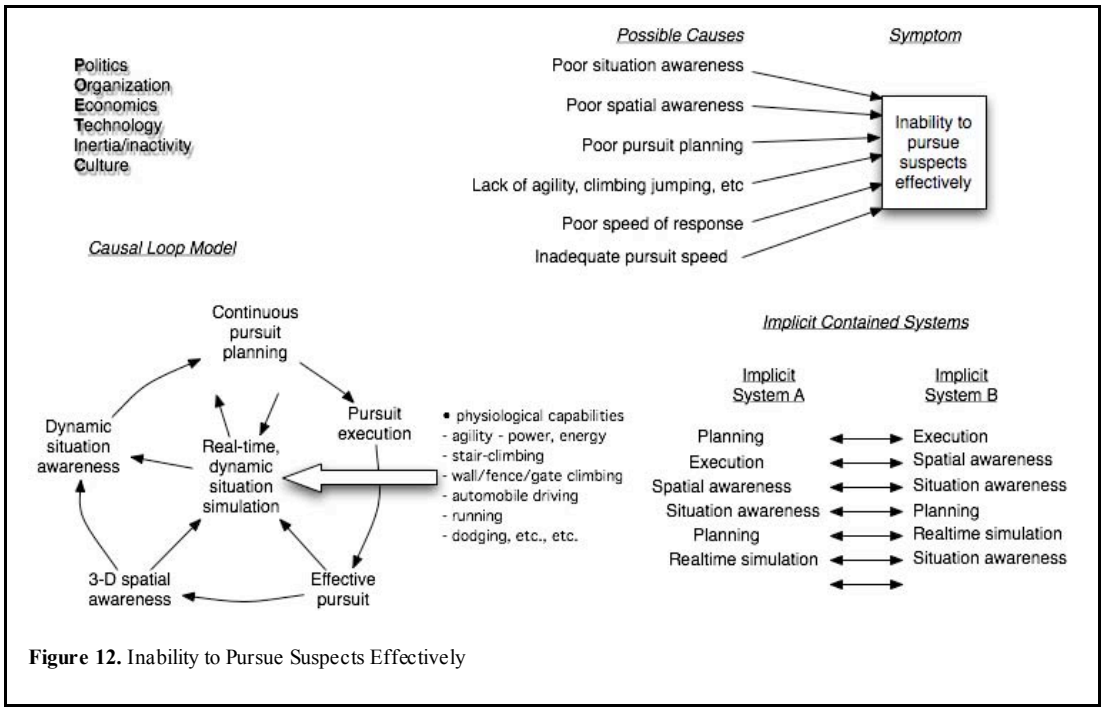


**Figure 12.** Inability to Pursue Suspects Effectively

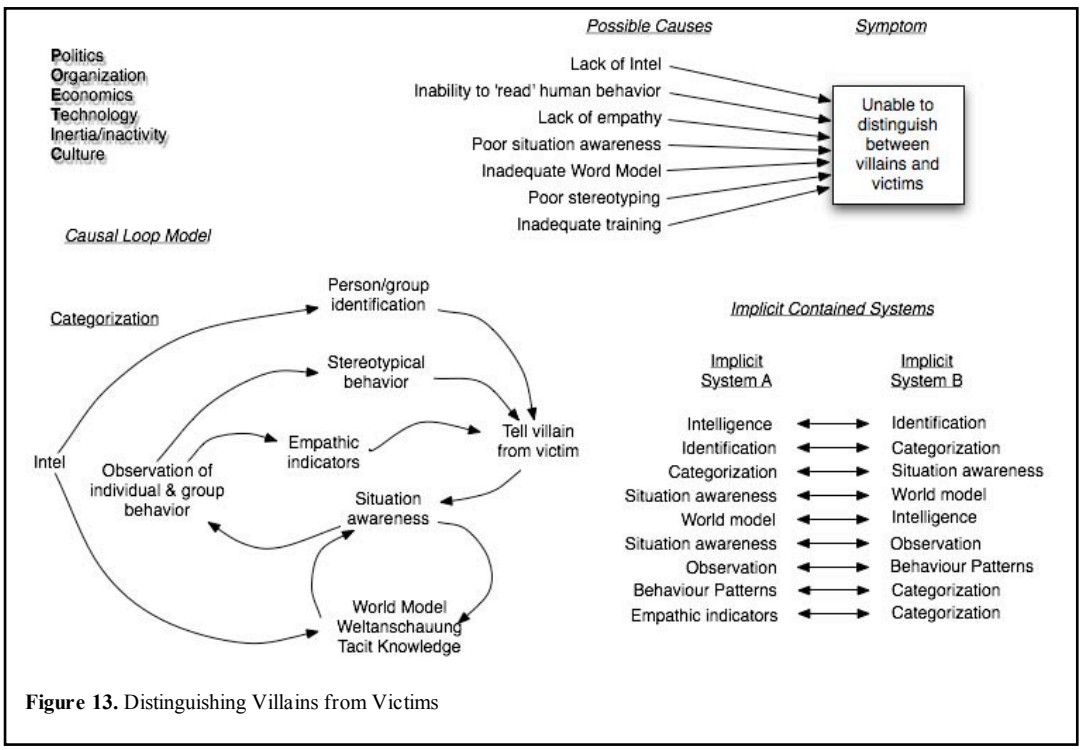


**Figure 13.** Distinguishing Villains from Victims

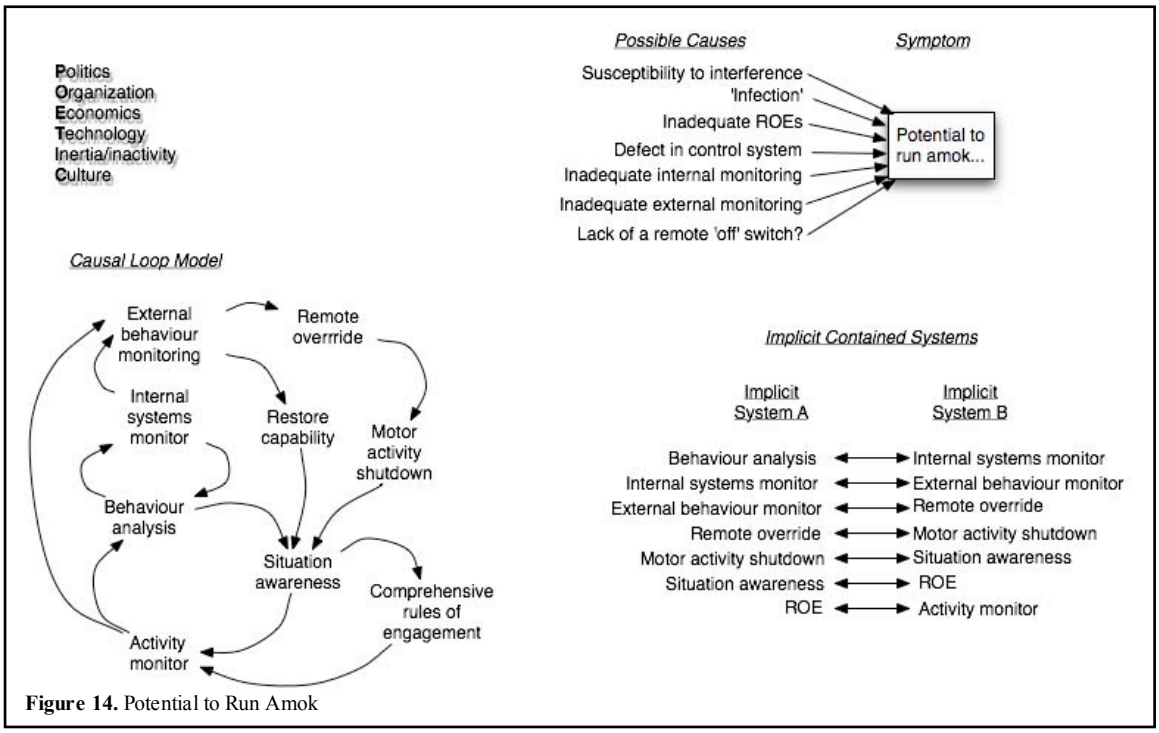


**Figure 14.** Potential to Run Amok

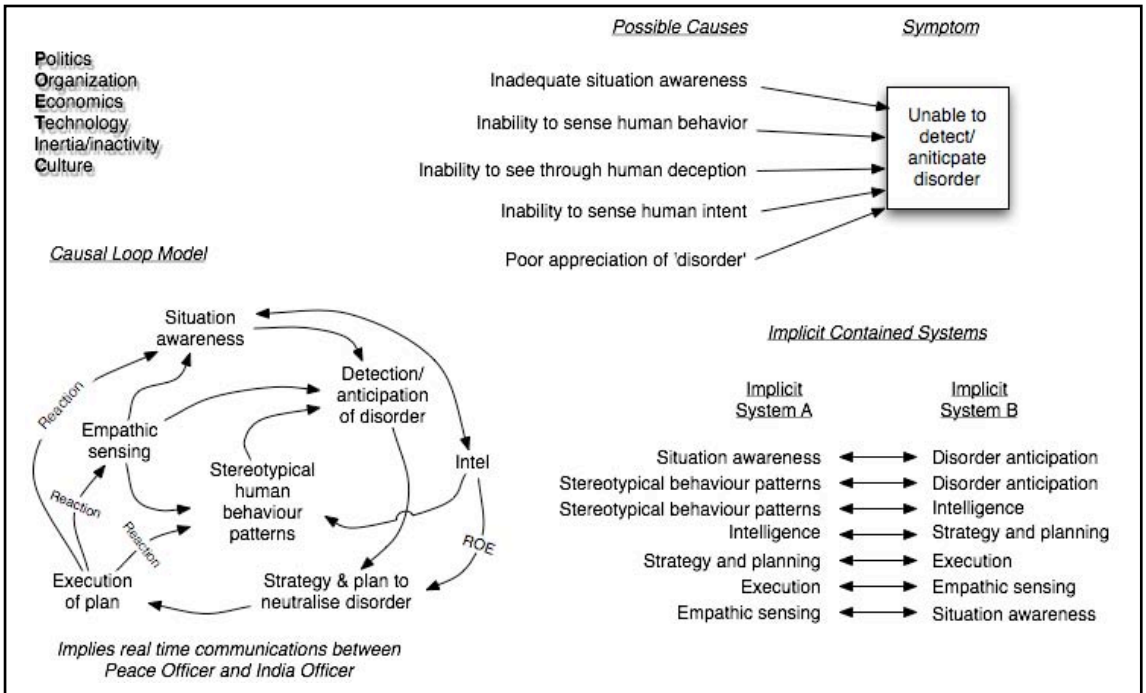


**Figure 15.** Inability to detect/anticipate disorder