## St Andrews University
## School of Computer Science Technical Report

# Carnegie Scholarship Research Project:
# *The Incorporation of Intentional Action into Robots*

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**Abstract:** Robot design has recently become a burgeoning area of research for intelligent computation and applications range over diverse scales, from robot insects to Mars explorers. Despite the human associations, standard robot dynamics has more in common with inanimate action than animate action. The Carnegie Trust Scholarship Research Project described herein is intended to redress the balance by addressing the question: How does a robot become able to act intentionally?

The question provides a focus for the project which will investigate into the fundamentals of robotic learning and action. The supporting experience in goal direction of the Intelligent Computation Group at St Andrews provides a unique opportunity for a novel answer to emerge.

### Detail

A *robot* may be defined as *a programmable, multifunction manipulator designed to move material, parts, tools, or specific devices through variable programmed motions for the performance of a variety of tasks* (Robot Institute of America).

The above definition includes robots which are pre-programmed and operate in highly structured environments such as industrial car paint sprayers. We are interested in researching a narrower remit, namely that of actively adapted artificial agents, whose environment is highly unstructured and unpredictable. These robots' worlds would be *continuous* - states and actions drawn from a continuum of physical configurations and motion. Also, these robots are *non-deterministic*, as there is uncertainty whether an action will work, and *non-episodic*, as the effects of an action change over time.

Robots currently take many forms, but one common theme is that the determinacy of their dynamics is designed to be the same as that of other *inanimate* objects. This can be readily seen in smooth behaviour where the common determinacy is (after environmental influences are accounted for) that the behaviour is *analytic*. That is, the behaviour is determined by its Taylor Series so that the future behaviour is a fixed extension of the present behaviour. By contrast, when an *animate* agent is being blown off course for the goal the behaviour is flexible enough to deviate back towards the goal.

This project supposes that robotic action may be made different from inanimate action, and made more similar to animate action, by making it intentional. The main question that we would wish to address is thus : "How does a robot become able to act intentionally?". Several thoughts follow on naturally from this;

(a) What features distinguish intentional behaviour from other behaviours?
(b) How would a robot be given the features of intentional action?

The Intelligent Computation Group at St Andrews has an approach based on the analysis in [1]. The analysis concludes that the features of *plasticity* and *persistence* characterise intentional behaviour. Plasticity means the ability to deviate from the present direction and persistence means the continual direction and redirection towards the goal. In everyday terms, intentional behaviour is flexible and tenacious.

These two features, persistence and plasticity, are modelled through a novel differential calculus based on *non-analytic* mappings, rather than the *linear* ones used in the familiar Newtonian calculus. This non-analytic property of the calculus is a key one, as it allows characterisation of intentional or goal-directed behaviour as being different from other basic types of behaviour.

The relevant fundamental types of behaviour are :

- Random behaviour : this is clearly plastic, but is not persistent in any particular direction.
- Standard determinate smooth behaviour : this is analytic, as described above. Such behaviour is persistent in the direction of the analytic extension. It is not plastic though, as it is unable to deviate from the projected extension.
- Goal-directed behaviour : This is characterised by non-analytic, non-random, behaviour. Such behaviour is able to deviate smoothly from the Taylor Series projection, to persist towards the goal when the series' projection is not in line with the goal. This behaviour can therefore be characterised as both plastic *and* persistent.

Importantly, the group's novel calculus also provides the basis for equations of motion analogous to those provided by Newtonian Calculus for elementary physics, e.g.$s = u.t + \frac{1}{2}a.t^2$ , where $s$ is distance, $u$ is initial velocity, $t$ is time, and $a$ is acceleration.

One existing project within the group has been investigating the application of the goal-directed equations using simple human movement as data. Our research would seek to simulate the smooth variation in this motion using an artificial neural net as a controller - thus allowing for ready application to robotics. The controller may then be tested on a physical robotic rig as well.

Another appropriate spin-off area for application due to the use of neural networks is that of heuristic search. This is currently dominated in neural networks by Newtonian Calculus methods, i.e. gradient directed methods. The Intelligent Computation Group has much experience in the manufacture of novel heuristic search techniques for neural networks. Steering models involving subgoal chains are used which are not gradient directed. [For example, the group's Tangent Hyperplanes technique has been shown to solve benchmark search problems more robustly and with substantially lower iterations than gradient based methods, (e.g. an average of 14 for XOR and 2,910 for a single hidden layer solution of 2 spirals) [2].]

This research should lead to many non-trivial applications of intentional robotics; in science, automated experimentation would become far more flexible, and autonomous exploration in hostile environments (volcanoes, space) would become practical; in industry, flexible assembly would be possible in ways that are unimaginable given the current generation of robots. There would be great humanitarian benefit too; elderly and the disabled could benefit from devices such as intelligent wheelchairs, capable of dealing with real world environments. The latter may in fact be investigated during the project as simple autonomous wheelchairs have been developed [3] and the group has access to wheelchair data from US psychologists studying intentional action.

The project is intended to have its underlying model of computation lead to something different'. Our project's 'difference' lies in enabling robots to act intentionally in a computationally novel, feasible, and distinctive manner. The specific benefits of intentionality in robots will be more capable and successful robots through their greater flexibility and tenacity. The general benefits are a greater affinity with robots as reflections of ourselves. If robots are to act as human surrogates they will need intentionality.

**References**

[1] *Goal-Directed Behaviour*, M. K. Weir, Studies in Cybernetics 6, Gordon and Breach,1984.
[2] *Using Tangent Hyperplanes to Direct Neural Training*, Neural Computation '2000, M. K. Weir , J. P. Lewis, G. Milligan, 2000.
[3] *Mobile Robotics 1997*, J. Bayliss et al, Technical Report 661, Rochester University, 1997.