NARCSim An Agent-Based Illegal Drug Market Simulation

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Abstract— **Combined forces interventions in the UK's illegal drug market can be designed and evaluated using a serious game, where the illegal drug market can be simulated using an Agent-Based Model with a many different classes of human behaviour. This paper presents NARCSim the Intelligent-ABM that powered an illegal drug market serious game, created to investigate innovative methods for training people working to reduce the effect of drugs on the community. NARCSim is an Agent-Based Social Simulation of the behaviours of Heroin, Cannabis and Cocaine users, dealers, police and treatment officers in UK. The agents' behaviour were formalised using X-machines and implemented on the agent-based framework FLAME.**

Keywords-component; agent-based modeling, FLAME, illegal drug market, serious game.

I. Introduction (Heading 1)

Computer simulations enable us to model, understand and make predictions in a large range of domains, where direct experimentation might not be possible. These models lie in a convergence of disciplines between computer science, mathematics and applied sciences (social or physical). Computational criminology also applies computer simulations to study topics of interest to criminologists (Berk, 2008) [1]. A simulation can be agent-based or equation-based. In the first case the agents encapsulate the behaviours of various elements that make up the system, and predictions are obtained by emulating all the individual behaviours at the same time. The second consists of a set of equations describing the phenomena involved, and the predictions are obtained by evaluating these equations together (Van Dyke Parunak et al, 1998)[2]. Since the creation of games like SimCity, the idea of creating artificial societies in which individual and organizations could be represented, and the effect of their interaction be observed, caught the imagination of social researchers (Gilbert, 2004)[3]. A further advantage is the fact that, in order to create the computer simulation, it is necessary to make any assumption explicit, modelling it exactly and give a value to every parameter [3]. This clarity and precision allows inspections by other researchers and gives insight into the '*emergence*' of macro phenomena from micro actions [3].

Simulations created to emulate the corresponding social phenomena can use any model that simulates social entities, from cellular automata (Hegselmann, 1998) [4] to finite state machines. Agent-Based Modelling (ABM) provides ability to specify the behaviour of an individual, or class of individuals, as a set of rules to observe emergent behaviour of the whole social system.

The research presented here is concerned with the synthetic recreation of the illegal drug market in UK. In order to design the rules of behaviour of each class of individuals (agents) involved in the illegal drug market, information has been collated from a wide range of data provided by literature and governmental institution [5,6,7, 37,38,39].

This paper describes an ABM approach to simulate the behaviour the illegal drug market as a group of autonomous individuals (agents), interacting amongst each other and the events induced by combined forces interventions in the illegal drug market. This simulation will be used in a virtual reality serious game for combined forces design and evaluation of interventions.

II. The Game Rationale

The serious game described in this paper has been commissioned by the Lincolnshire Drug and Alcohol Action Team (DAT). The initial game idea was conceived by the DAT development manager: Rankin Barr as a board game based on a 25 sq metre model of a difficult estate[1]. The board game, shown in figure 1, has been used in a pilot trial by five convicted drug dealers playing against and drug treatment professionals. The dealers were asked to have a look at game's model and set up a dealing network here and explain what they would do to set it up. The opposite team, comprising of a mix of senior drug treatment decision makers and street-level workers, was also asked to reason on a preventative strategy against the dealers' actions.

[1] http://www.guardian.co.uk/society/2005/mar/30/guardiansocietysupplement3

Figure 1 The Drug Market simulation board game

The NARCSim was born from the idea of developing an electronic version of the board game for DAT personnel and other forces to use. It was created as an innovative method for providing decision making training to personnel working towards reducing the effect of drugs on the community. NARCSim provides an insight into the world of drugs dealing and crime fighting and the effect actions have on the community, allowing the players to explore current working practice and improve strategies and planning for the future.

III. MODELLING AND VISUALIZING HUMAN BEHAVIOUR WITH AGENTS

Real-world human actions do not just occur based upon logical, deductive reasoning; behaviour is also based upon experience inferring conclusions by induction and through social interactions. In a social context the single parts and the whole are often very hard to describe in details (Remondino, 2003) [8], intelligent agents can act as basic building blocks of an artificial society and be used to study the emergency of the social behaviour. Agents can be autonomous, flexible, adaptable and goal-directed. In the latter they are referred as intelligent agents. ABM provides a bottom-up approach to describe a complex system, such as human social behaviour, capturing emergent phenomena.

Gilbert [3] states that human societies are such that the behaviour of the system as a whole cannot be determined by partitioning it and understanding the behaviour of each of the parts separately, which is the classic strategy of the reductionist physical sciences. In human society there are many, non-linear interactions between people. The interactions involve the transmission of knowledge and materials that often affect the behaviour of the recipients [3]. "*The individuals within a society are constantly 'in motion': talking, listening, doing*."(p3)[3]

Society emerges from this constant change and the result is such that it becomes impossible to analyse it as a whole by studying the individuals within it one at a time. Furthermore individuals vary greatly in their capabilities, desires, needs and knowledge, unlike most physical systems, which are composed of similar or identical units [3]. Behaviours 'emerge' from the actions of these diverse units in constant motion.

A review of agent-based social simulations (ABSS) is presented by Li et al. (2008)[9]. For example SimPan (Schneider, 2008) [10] is a simulation that uses ABM to model human panic behaviour based upon established psychological theories and findings. Also Urband & Schmidt (2001)[11] have introduced PECS, a reference model for the construction of human-like agents, considering the physical, emotional, cognitive states of the agents. PECS models basic social psychological mechanisms in the context of group formation and disbandment with ABM. PsychSim (Marsella et al., 2004) [12] is an ABM that gives the agents a theory of mind. It is a multiagent based simulation tool for modelling interactions and influence between groups or individuals, where each agent has its own decision-theoretic model of the world, including beliefs.

Thespian (Si et al., 2005)[13] is a framework for realizing interactive drama that seeks to reduce programming effort by providing the author a linear scripts of the drama, which an automated fitting algorithm then configures to the behaviour of the agents.

Apart from the the need to explicitly specify any assumption and parameters' value in an agent-based model, the greatest difficulty for simulating synthetic society is the need to have the appropriate data set. Traditionally social scientists rely on qualitative data acquired trough observation of the natural phenomena to conduct their work. To create an ABSS instead quantitative analysis of the phenomenon is required.

Sociometric surveys treat individuals as isolated atoms and pay little attention to the interactions amongst people [3]. Also, they measure the sociological system at one moment in time, making society changes invisible [3]. What is needed is data that tracks the behaviour of individuals over time for a sufficiently wide period to capture the emergent phenomena. To overcome this limitation, models based on the data available are often created. These are subsequently calibrated further when additional data becomes available. The latter is the approach taken in the presented research for modelling the UK Illegal drug market. This ABM will be, no doubt, subject to future validation and calibration when more refined data is acquired.

IV. EXISTING ABM FRAMEWORKS

There are various simulation / modelling systems in literature: SWARM [14], Repast [15], NetLogo [16], MASON [17], Cormas [18], to mention a few. Each supports their own modelling format (and in some cases visualisation system).

Understanding these frameworks and their internal modelling format hinges on the quality of the documentation and tutorials provided. A review is given in table 1, where the characteristics of each model are featured, such as the programming language they support and whether or not they are open source, the availability of tutorials, whether or not they support parallel processing, the raster space, the vector space, and the modality of data visualization.

TABLE I. REVIEW OF EXISTING ABM FRAMEWORKS

Name	SWARM	Repast	NetLogo	MASON	Cormas
Language	Objective C, Managed C++, Java	Java, Python, .NET	Scripting	Java	SmallTalk, Scripting
Tutorials	Yes	Yes	Yes	Yes	Unknown
Parallel	No	No	No but the original Star Logo was targeted at a parallel machine	Yes – each agent is stepped with the same function through a scheduler	No
Raster Space	Yes	Yes	Yes	Yes	Yes
Vector Space	Yes	Yes	No	Yes	No
Visualisation	2D	2D, 3D expected with Repast SIMphony release	2D, basic 3D	2D, limited 3D	2D Grid
Open Source	Yes	Yes	Yes	Yes	Yes

In particular SWARM is a library of object-oriented classes for ABM (Swarm.org, 2007) [14]. Originally written in Objective-C for Unix, is available in Windows through the use of the Cygwin Unix simulation environment and bindings for Java have been provided to access all functionalities. The SWARM documentation features a thorough guide for implementing a SWARM based system. The '*model swarm*' is the collection of Agents and a world in which the agents interact. The model swarm alone is insufficient for the system so an '*observer swarm*' of observing objects is used to input data into the model swarm and read data from the model swarm. The SWARM Library documentation lists a number of classes, grouped into libraries that provide a variety of functions that are suitable for implementing Agent-Based Models. These libraries provide GUI frontends, representations of space, and representations of agents, agent visualisations and check pointing of the state of the model through I/O operations. The GUI libraries provide access to all of the standard GUI components like text-fields and buttons. The analysis library provides functionality for analysis of the data in graphs and visualisations of agent positions. MASON, is multiple agents framework (George Mason University, 2008) [17], written purely in Java with a well documented API. It also includes facilities for visualizing the agents in a 2D or 3D (Luke, Cioffi-Revilla, Panait, & Sullivan, 2005) [19]. No additional libraries other than MASON and Java SE are needed to run and visualise an ABM. Using the visualisation increases the memory usage, and not mandating the use of a visualisation and it can help to increase the maximum number of agents in use. The visualisations support multiple layers so different types of agents can be distinguished from each other and elements of the environment [19].

Whilst each of these frameworks is relatively intuitive, the scale of modelling is restricted when real time constraints are added. Single machine ABM frameworks simply do not demonstrate enough power for the simulation of large or highly complex systems. To date the alternative has been to create and use a high performance grid-based ABM. The FLAME (Flexible Large-scale Agent-based Modelling Environment) framework [20] is an example of this. FLAME is an X-machine (Holcombe, 1988) [21] based framework for parallel processing, which supports message passing of agents on a large grid of computers. FLAME has been developed by a team at the University of Sheffield (Holcombe et al., 2006) [22] and has a great flexibility in its usage. In fact it has been extensively employed to model complex biological and economical systems. In FLAME every agent is abstractly represented like a state machine, all the processes occurring are specified using a XML-like format and they all share a common special memory component that allows agents to communicate and store information. No standard visualization mechanism is provided by FLAME, but the data is visualised ad hoc, according to the type of system it models. For example (Romano, Gheorge, Swartz, 2009) [23] used a 3D graphics representation for visualizing the real-time behaviour of bacteria quorum sensing and a 2D graph to visualize the behaviour over-time.

High performance grids are expensive and not available to the majority of ABM modellers, impractical for the use of ABM in virtual reality serious game. Richmond, Coakley and Romano (2009) [24] have implemented Unified Device Architecture (CUDA) versions of FLAME, GPU FLAME, that run on NVIDIA graphic cards. FLAME GPU [24] uses the formal agent specification language of FLAME (XMML) but maps the computation of agent functions and agent communication to the GPU (Graphics Processing Unit) through dynamic CUDA code creation. This results in a massive performance increase, which has been reported to be up to a 250x speedup over a single CPU alternative. FLAME GPU computes the agents' behaviour and their visualization at the same time on the GPU. In addition having the visualisations executed directly onto the GPU eliminates the bottlenecks of having input-output files transfer from host to GPU memory for rendering. Not only does this preserve the ability to simulate massive populations, it also allows real-time visualisation and dynamic interaction with models required in a game-like scenario.

The speed increase is a real advantage if ABM is to be used to simulate a social system of a wide community within 3D graphics serious-game, as it is the aim of the research presented here, with the limitation that the created serious game can only run on operating systems that NVIDIA supports.

V. TOWARDS AND ABM DRUG MARKET SIMULATION

There are a large number of factors that affect how a population acts in the drug market. In order to build a simulation, these factors must be isolated and their effects on the variables in the environment and the agents themselves must be made explicit. The varying factors can belong to the agents themselves (e.g. addiction level, money, health) or to the environment (suitability of the area for drug dealing, presence of police stations). The agents' rules of behaviour should be clearly defined in formalised rules, based on human-expert knowledge.

The behaviour of the Agents can be defined in terms of *environmental constants* (e.g. geography), *rules of behaviour* (e.g dealer-addict behaviours) and *factors* that will vary as the system is executed (e.g. cost and availability of drugs). These defined rules can then be translated into an Object Orientated (OO) approach using the principles from OO design. The defined rules and structure of agents can be translated to common OO diagrams and schemas to implement an ABM.

FLAME, GPU FLAME and MASON frameworks all use OO to define each of the agents and their behaviour. FLAME and GPU FLAME uses and XML approach and a given syntax for specifying the agents and rules.

The model will be stochastic (LeBaron, 1998) [25] in nature due to using rules that are necessarily non-deterministic be of the probability of certain outcomes in the defined rules. This means that there will be a variation of possible outcomes.

VI. HUMAN BEHAVIOUR UNDER DRUG

In order to accurately code the agents' rules of behaviour in an illegal drug market, the effects of drug use on human behaviour before, during and after must be understood and modelled. It is difficult to produce quantifiable measures of effects associated with substances as the experiences while taking drugs is subjective to the user (Gene & Henry, 1962) [26]. These effects can be categorised as *psychological* and *physiological,* and have two periods: the action (or '*high*') and the withdrawal (or '*comedown*'). The *high* affects the user's behaviour soon after the drug has been taken, the *comedown* lasts for a longer period of time after the high has ended (Oakley, 1978) [27]. There are factors that affect the intensity and lengths of these two periods such as the type of drug, the users' tolerance and if there has been repeated use.

There is no universally recognised method for measuring the effects and symptoms of drugs, as the experiences of taking drugs is highly subjective [26], but a number of different methods that have been employed in various studies. Smith & Beecher (1962) [28] have produced a list of possible symptoms and asked a number of test-subjects if they had any of the symptoms over some time. By separating effects into physiological and psychological ones, the effects that are most relevant to the system can be identified for implementation. In Table 2 a summative matrix of the effect of the drug that have been considered in the illegal drug market.

TABLE II. A MATRIX OF THE SUBJECTIVE EFFECTS UNDER ILLEGAL DRUG AND SPYCHOLOGICAL EFFECTS

Effect	Heroin	Cannabis	Cocaine/Crack	Ecstasy	Meth
Anxiety Relief	Y	Y	Y	Y	
Drowsiness	Y	Y			
Confusion	Y			Y	Y
Euphoria	Y	Y		Y	Y
Nausea	Y	Y			Y
Impaired Reactions	Y	Y			Y
Psychosis	Y	Y			Y
Depression	Y	Y	Y	Y	Y
Loss of Concentration	Y	Y	Y	Y	Y

Subjective physiological effects are replicated in the simulation by considering how they alter one's abilities to function, movement and perception.

Addiction is also important. Psychological addiction is the result of repeated behaviour and is also called dependence.

Symptoms of psychological addiction come from formed habits and rather than the physiological need for substances. Dependence comes from a repeated behaviour to a point that the individual feels that s/he cannot live without the stimulus produced by the drug, which compels them towards the repeated behaviour. Any behaviour that results in a change of mood through a reward a reward mechanism in the brain can result in a psychological dependence, so mood-changing drugs can all result in psychological addiction. This can be simulated in agents so that an agent's past exposure to drug effects the behaviours it chooses in the future.

Physical addiction is given only by those substances that elicit severe *withdrawal* symptoms in the user when the substance usage is discontinued. A sudden removal of the drug (colloquial referred to as 'cold turkey') can produce serious side effects so physical addiction is often treated with a controlled lowering of the dosage of the substance to wean the addict off. The difficulty of stopping usage of physically addictive drugs tends to be much worse as the withdrawal effects are more severe than any psychological withdrawal effects.

Some substances may appear to be physically addictive because they have a reduced effectiveness after repeated use (desensitisation). Users often need a greater dosage in order to receive a *high* similar to when drugs are first used. This can also represent an increased risk as user may also increase chances of overdose.

Furthermore changes in behaviours, associated with the use of illegal drugs, can lead to changes in social conditions with a significantly large number of users. Measures of social conditions have been found in studies on the effects of drug usage at the higher-level of societal impact. Measures of social conditions also help in the analysis of correlation between a numbers of factors. For example, one might notice that in areas where there is a high concentration of habitual drug users, the percentage of unemployment rises (MacDonald & Pudney, 2000) [29]. The use of some illegal drugs alters the sleeping patterns and ability to work due to effects such as depression, anxiety and confusion. These psychological symptoms increase the likelihood that a drug user will lose the job, or s/he will not seek employment as the sustaining of drug addiction becomes the first priority in a users' life. Also there is a correlation between crime and a large percentage of illegal drug addiction within a given, shown in the statistics from a number of studies (Home Office, 2007) [7]. The term '*drug related crime*' is used to signify crimes other than drug distribution (which is itself a crime) that are caused by the organised crime required to get drugs into an area, and crime associated with addicts committing crime to obtain money to feed their expensive habit. This can be modelled by setting the level of addiction where the potential for an agent to commit crimes such as burglary and mugging increases.

Agar, (2005) [30] has shown that physical areas containing illicit markets are not as isolated as we often think. There are a large number of factors, such as employment and educational background of the residents, that influence the behaviour of an illicit market beyond the obvious supply, demand and human population concentrations. These factors can be seen as a consequence of the breakdown in the *quality of life* in an area. Though these factors are obviously important to the identification of an area where an expansion of illegal drug markets may occur, they may not have a proportional impact on the behaviour of its inhabitants and consequently these factors may not be useful in constructing an ABM and just add to the complexity of the rules. The wealth of information and studies into illegal drugs (with much focus into the Psychological effects of addiction (Robinson & Berridge, 2001)[31], with some even producing quantification of effects (Becker & Murphy, 1988)[32], can provide the basis for constructing rules suitable for implementation in an ABM. However, there is the danger that the model will be overly complicated and provide little to no benefit to the finished system.

VII. EXISTING DRUG MARKET & CRIME MODELS

The SIMDRUG (Perez & Drey, 2005)[34] is an ABM model for exploring the complexity of heroin use in Melbourne, Australia in order to improve interventions. The type of agents used were cellular-automata. In SIMDRUG one modelling time step is equivalent to a 24 hour day in reality and each simulation is run over a 5-year period. They have used real data on heroin use in Melbourne considering 1998-2002 as the reference period, and performed an *Internal Quantitative* validation of the model. The city itself has been considered in the system as being based on a regular 50x50 square mesh, where the grid size been chosen according to the number of users (3000) and dealers (150) to be modelled and located in the environment. They do not use real Geographical Information System (GIS)-based data for the city since they mainly focus on social behaviours and interactions.

The city is divided up in street blocks, where the main characteristics, such as crime, overdoses, fatal overdoses, wealth, environmental risk and attractiveness for drug dealing (conduciveness) are locally recorded. At each time step the environmental risk is calculated as in the formula 1 below, where "No" stands for the word "Number".

$$\text{Risk} = (10 * \text{No\_of\_crimes}) + 10 * \text{No\_of\_overdose}) + \text{No\_of\_users\_on\_the\_street\_block} \quad (1)$$

One street block becomes conducive (i) if there is a dealer or (ii) if risk > 20 or (iii) if there are at least 4 conducive street blocks around. One street block becomes non-conducive if there is no dealer and (i) if the risk = 0 or (ii) if there is at least 4 non conducive street blocks around.

SimDrug has different types of agents: users, dealers, wholesalers, constables, and outreach workers. Each group is simply represented with minimum set of characteristics and dynamics that allow the social simulation to display most of the properties of the real population.

Another relevant model is BurgdSIM by Malleson (2007) [35], who has created an ABM to predict urban burglary rates in Leeds to help investigate how new developments will impact on crime rates. The model has been based on a body of literature on the factors behind crime in particular two theories have been tested in the model: the Opportunity Theory and the Routine

Activities theory, to determine whether an offender will commit a crime. Research indicates that offenders are less likely to plan to offend, but offenses seem to rise from chance meetings between the offender and the target in an atmosphere lacking suitable guardians. Malleson [35] has used real data between 2001-2004 provided by Leeds Community Safety Partnership and divided into "wards" where offenders lived at the time of the crime. Further demographical data has been taken from the 2001 UK Census of Population and WICID (web-based Interface to Census Interaction Data) system, which describes the flow of people between origins and destinations. Geographical data about Leeds has been taken form UKBORDERS and Digimap. The first provided boundary data and the second the roads and other transport network existing in the considered area. To validate the system the standardised root mean square error (SRMSE) has been used.

VIII. NARCSIM

NARCSim is the name given to the ABM presented in this paper, which runs on the FLAME framework and will be used to drive the illegal drug market serious game. NARCSim constitutes the heart of the serious game, but a graphical frontend is also being built to visualise the simulation outcomes. FLAME is used to allow the simulation to work on one single machine rather than on a GRID and visualise the output of the model in real time, so that a time step of NARCSim corresponds to a time step in the serious game animation. This will allow to see the effects of the planned intervention in real-time.

NARCSim is being used to power the agents/human in the simulation to show how the illegal market in UK and crime data evolves over time. NARCSim emulates the illegal drug market, based on data on the Home Office publications. An algorithm for the automatic construct 3D residential neighbourhood in UK has also been developed by Richmond & Romano, (2007) [36] and is used generate the GIS-based 3D model of the area under observation suitable for simulative training. NARCSim is concerned with the market of Heroin, Cocaine/Crack, Cannabis, Ecstasy and Meth, and the crime rate associated with the areas where drug dealing and consumption take place. As such NARCSim considers more aspects than just the Heroin market as in SIMDRUG (Perez & Drey, 2005) [34] and only drug-related crime, unlike BurgdSIM (Malleson (2007) [35] that modelled all crime types in the city of Leeds.

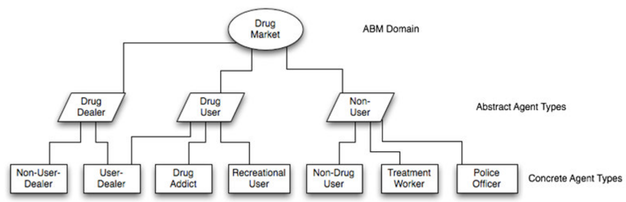

Figure 1 A diagram of suitable agent roles featuring the use of Abstract Agent Types

The human behaviour considered in the simulation, has been categorised into three general categories: Drug Dealer, Drug User and Non-User. These can be further divided into six groups of people: non-user-dealers, user-dealers, drug-addict, recreational-user, non-drug-user, treatment workers and police officers, as it can be seen in figure 1. The classes and subclasses dependencies are shown in figure 1. The case of Police_officer or Treatment_worker agents belonging to any other group rather than Non-User has not been considered.
A description of the agent types considered, their parameters and the way their role might transform over time is described below:

Non-User-Dealer – An agent that can sell a range of drugs to any agent in the world that wants drugs. Is capable of becoming a User-Dealer by using his/her own supply.

User-Dealer – An agent that sells a range of drugs and also uses from its own supply. Can become a Non-User-Dealer if it does not consume drugs for a long time.

Drug-Addict – An agent that needs to buy drugs from a dealer in order to sustain a habit. That is it has a physical dependency. The effect of drug use will be expressed in the agent such as paranoia and according to the table 1 above. The agent main goal is to obtain money, including becoming a dealer or commit crime, if sufficiently addicted, and without an income capable of sustaining an addiction. Can become a Non-User if they are successfully treated by a treatment worker

Recreational-Drug-User – An agent that is not addicted to drugs but will occasionally buy drugs from User-Dealers agents and exhibit behaviour caused by consumption of drugs; such as the 'high' and the 'comedown'. It can also have a psychological dependency and become a drug addict (physical dependency) if it consumes sufficient drugs over time or a Non-user if they do not consume any drugs for a long period. It can also become a User-Dealer, in this case it will buy drugs in larger quantities. Apart from drug dealing, it has a smaller chance to commit crime.

Treatment-Worker – An agent that tries to change Drug Addicts into Non-Users

Non-User – An agent that exhibits no drug-related behaviour except for the slight chance of becoming a recreational drug user.

Police – An agent that seeks to stop Drug Dealers, e.g. by arresting them, and those who are committing crimes. Also acts as a deterrent to stop agents that are about to commit crime, also dealing, when a crime-committing agent can see them.

From these definitions the agents behaviours can be written as a more formalised definition of agent behaviour. As for example in figure 2 is the pseudo-code for an agent Drug-Addict.

```
Addict
if lastFix>withdrawalTime &
   lastFix<coldTurkeyTime
       addictionLevel++

if lastFix>coldTurkeyTime
       addictionLevel—

if addictionLevel<fixThreshold
if money<minimum_cost_drug
       crimePotential++
else if
closestDealerDistance<dealDistance
       deal closestDealer
else if
closestDealerDistance<viewDistance
       approach closestDealer
if crimePotential<crimeThreshold
       commitCrime = true
if commitCrime
if closestAgentDistance<mugDistance
       mug closestAgent
else if
closestAgentDistance<viewDistance
       approach closestAgent
else
       seek agent
```

Figure 2 Pseudo code for agent role Drug-Addict

Definitions of variables and constants in the system can be obtained from real world statistics. For example, 'coldTurkeyTime' is a constant that can be obtained from statistics of the likelihood that an addict, who hasn't had a fix for a number of days, will lower their level of addiction. More complex and individual agents can be made through the usage of agent variables such as the 'addictiveness' of an agent that will vary based on a representation of how addictive a personality an agent has.
The NARCSim behaviour is coded in C. Also a simple Java Frontend for the visualisation of data output in space has been created and it is shown in figure 3. A Class representation of some of the Agents and all Drugs has been constructed using

the OO rules of inheritance for Agent memory. Agents can be created in the frontend using constructors for Agents. The default constructor creates an Agent at a random position between the min and max coordinates and additional constructors allow full definition of variables such as the Agent's money. The Java Agents are then converted to XML and used in the FLAME Executable. The output from the FLAME Executable is converted back into Java Objects for visualisation and/or manipulation of Agent Variables for feedback/refinement.

The Creation of the agents can be done in the Simulation Construction Screen. This sets up the number of agents and their corresponding variables. Bulk creation of Agents can be achieved by creating a desired number of random agents. This creation screen then creates the XML and dispatches the XML to the FLAME executable.

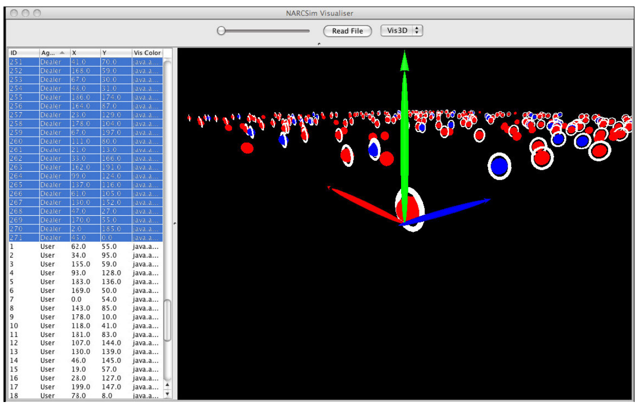

Figure 3 The basic visualization of agents' positions

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IX. EVALUATION

According to (Berk, 2008) [1] the validity of the simulation depends on whether the model is able to reproduce empirical phenomena with sufficient accuracy, and the only way to determine it is to compare the output of the model to real observation.

Though there is a decent supply of statistics for factors effecting Illegal Drug markets, it has proved difficult to find detailed data for variations in neighbourhoods over a period of time. Instead of specific data points to analyse the system, general trends can be found from the real world data. Due to the lack of specific information about types of neighbourhood from the set of statistics, analysis criteria need to be derived from trends shown in real world data in order to train the system. Several criteria can be found in literature that can be used for testing the model, where a change in one input variable, can have an effect on more than one output statistic.

The criteria found in literature with regards to the population density are reported below. For example criterion 1) below means that by increasing the population density (input variable), the percentage using (output statistic) will increase (trend). The sources for the criteria below are set in the *Home Office – Geographical Variations in Drug Usage* [37] and *Home Office – Measuring Different Aspects of Problem Drug Use* [38], *Independent Drug Monitoring Unit Website* [39]. The criteria found with regards to population density are as following:

1) By increasing the population density of model the ability for *Users* to acquire drugs will increase as will the ability for *NonUsers* to acquire drugs. (pp 12- 13 and pp 34-40) [37].
2) An increase in population density should mean that there is more money available in *NonUsers* for *Users* to sustain their drug habits. An increase in population density should also have an increase in the number of dealers and drug abuse, therefore *Users* will have an increased chance of trying a drug for the first time. (pp 12- 13 and pp 34-40) [37].
3) An increase in population density means that there is both more *Users* and more *Dealers*, therefore there should be a greater number of deals occurring since a *Deale*r is more likely to be near a *User*; and *Users* have the potential of more money in the form of mugging *NonUsers*. An increase of the number of police should combat the rate of this increase. (pp 12- 13 and pp 34-40) [37].
4) An increase in *population density* means that there are more *Users* and *NonUsers* in the same space. Since *Users* require money, they should be able to find *NonUsers* closer to themselves and as a result there should be more muggings. (p34 [38]; pp12-13 [37])
5) An increase in population density should result in more crime. This increase in crime along with population density increasing the number of *NonUsers* should result in the perception of crime increasing. (p34 [38]; pp12-13 [37])
6) An increase in the population density should result in an increase in the number of people using drug. This increase should therefore result in an increased potential for the number of overdoses, as an increased number of Agents will be taking drugs [39]
7) An increase in the population density will result in an increase in the amount of crime occurring. Therefore the number of Arrests for crime will increase as it is more frequent.

One important assumption made in the simulation is that *Police* and the *Treatment Workers* are not considered to be contributing to the population density of the area since they are not involved with money or drug dealing in any way.

To keep the results correlated with the change in input variable only, steps have to be taken to insure that only the input variable is varied over the range of values for the input variable. For the population density to vary, the ratio of Agent

Types must be kept the same, as well as the constants associated with them. The only input variable that should be changed is the total numbers of Agents, which are in the same ratio across all population densities. Increasing the population density will also have the effect of increasing the numbers of all agent types, but all agent types are increased so that the ratio of the agent population remains the same.

Figure 4, 5 and 6 show how the population density variation as forecasted by NARCSim in the various part of a city over 250 iteration of the model.

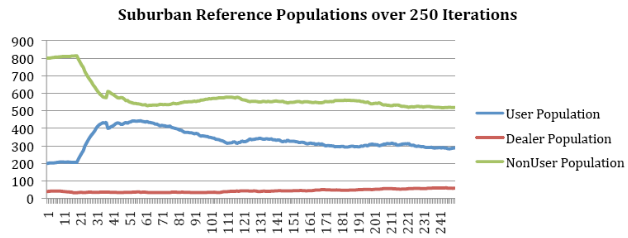

Figure 4 Sub-urban Reference populations over 250 iterations

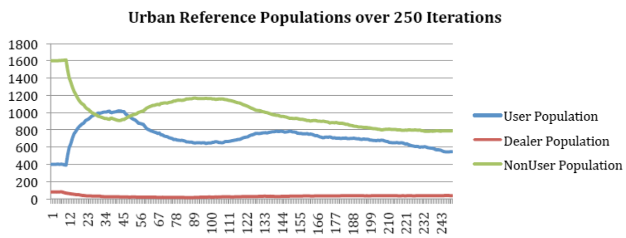

Figure 5 Urban Reference populations over 250 iterations

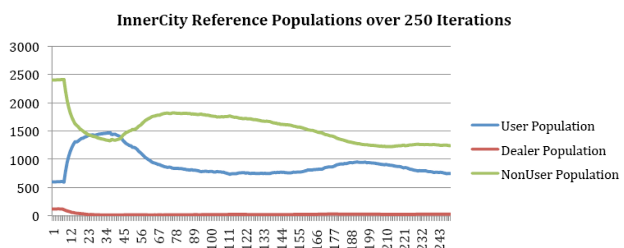

Figure 6 Inner-City Reference populations over 250 iterations

As shown in figure 4, 5 and 6 the populations in the urban sub-urban and inner-city population clearly show that the Dealers maintain the same number over time as their number find a sort of equilibrium, while there is a strong relationship between the relative numbers of *Users* and *NonUsers* over time. The negative trend of both, over time, represents the overdoses that occur removing agents from the system, rather than moving between types. A drop in the dealer population causes a lagged change of *Users* to *NonUsers* as the agents have a lessened supply of drugs, therefore increasing the likelihood that they will be able go *cold turkey*.

X. Results Analysis

The results of the evaluation of the system show that the system mostly follows the trends set in criteria found in literature.

A key feature of some Agent Based Model systems is that there can be some behaviour that the Agents appear to exhibit, other than the ones originally defined in the implemented functions. This is called *Emergent Behaviour* and can provide interesting insights into how real-world systems work.

One of the emergent behaviour highlighted by NARCSim is that *Users* can become addicted to other drugs when a dealer does not have drugs of the same type that the user requests, that are also less than the User's total money. If the agent gets an alternative drug and has a drug of this type a sufficient number of times, then it can become addicted to that drug.

This matches up with the real world concept of '*gateway drugs*', whereby taking an illegal drug of relatively low harm requires the individual to go to a dealer. This can have the appearance of lowering the sensitivity to commit crime; therefore an individual trying one of these drugs is much less sensitive to committing illegal acts. The individuals' perception of the harm that drugs can cause is consequently lowered, fighting against much of the education given by Schooling and Society that all illegal drugs will always be harmful to the User. A user of Cannabis in the system is also exposed to the selling of the much more harmful Cocaine and Heroin.

XI. Conclusion and Future Work

This paper shows how the illegal drug market can be simulated through a serious game for designing and planning multi-service interventions with an agent-based model. Data relevant to Illegal Drugs markets in the UK has been collected to be used in the system and to validate it. NARCSim is powered by the AMB framework: FLAME and can run on a single machine and provide immediate feedback on the effects of any interventions on the drug market in real time.

The current serious game could be extended as described below. Currently a 2½D frontend has been built to visualise the data in output, this can be replaced by a more user friendly interface in order for the ABM to be usable to more people than those with detailed computer knowledge graphical interface for the alterations of the input parameters to be provided to the simulation. The game could also be extended to include a representation of the agents in space. Also it could be turned into a fully 3D serious game, where the movement and interactions of the agents are visualised through animated characters in a virtual world. This representation would provide a more immersive experience to the users with a possible impact on training. In this case the user would not be simply observers of the agents' behaviour, but be able to drive an avatar and the users' decision and actions in the game world would affect the whole system. For example the user could kill a drug dealer and see the effect that this has on the cost of drugs. This could have a knock on effect on the number of addicts and the crime rate.

Furthermore there are other correlations between measurable criteria and the level of drug usage that have been identified in literature from real world studies. For example considering the social context in which drugs are taken, the age, gender, education sexual preferences, of the drug users and their social activities, e.g. nightclub customers are more likely to use Amphetamines and Ecstasy (Parker, Aldridge, & Eggington, 2001) [40], might provide further insights and further emergent behaviour could be observed.

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