ABSTRACT
Resources in games are becoming more important today as the expectation of the gamers is ever increasing. This is especially true for Massively Multiplayer Online Games (MMOG). The game designer needs to handle the mass amount of resources available. Besides, the designer needs to make sure that the game architecture used are robust and scalable to meet future enhancement. The purpose of this paper is to review from the literature some of the resources available in most MMOG. Our contribution is to map those resources to states and state transition functions in games. These state functions will enable future work in designing a better resource management and control system.

Keywords
Resources, games, states, state transition functions, MMOG

1. INTRODUCTION
Massively Multiplayer Online Games (MMOGs) have gained much attention recently. However, the design of such games is becoming more complex with the ever increasing demand from the gamers. On one hand, the designer needs to handle the mass amount of resources available and on the other hand the game architecture needs to be robust and scalable. The purpose of this paper is to investigate the resources available in most MMOG and attempt to map the resources to states and state transition functions in games.

The term “resources” refers to items used in support of some activity that need to be drawn from an available supply of resources. More importantly, resources need not necessarily have physical properties (e.g. entrepreneurship and education are important resources). Resources can also be defined as the things used by players and other agents to reach goals [1]. In the context of this paper, resources refer to in-game resources that are typically present in most games. These in-game resources and the management of these resources significantly contribute to the experience involved in playing a game. In turn-based strategy games, examples of resources include Gold, Oil, Units, Land Area and other useful and quantifiable objects. First-Person Shooter games contain resources in the form of ammunition, health and weaponry.

Resources can exist within the game or they can be an external game-related entity. Materials, People, Mana and Health are example of in-game resources. External game resources include functional components such as Save games or Lives. The relative value of a resource is determined by looking at the relationship between utility and scarcity [2]. Economics are related to resources and are closed systems of supply, distribution and consumption.

From the review of the literatures, resources in games can be classified into mainly six different types, namely Basic Resources, Secret Resources, Limited Resources, Non-Renewable Resources, Renewable Resources and Closed Economies [3]. These are summarised and presented in this paper. For each of the resources, we will first describe what we have reviewed and we will then map the resources to some basic states and state transition functions. The contribution of this paper is thus to extend the described resources and formulate them into appropriate states or state transition functions for use in modelling.

2. Basic Resources
Basic resources are Game Elements that are used by players to enable actions in a game. They are best described as the representation of a commodity that is used in the game to fund actions. Conversely, resources can also be depleted by other players’ actions [3]. Resources can be physical or virtual. Common resources can include health, ammunition, money, units, hit points, Mana points or simply some form of action points. Common resources vary with genre, as such it is not possible to list a common set of resources that is useful to all games. However, the basic behaviour of resources can be described as in Figure 1.

A generalised model of resources can be useful in winning a comparison with other players. This can be done by making use of an evaluation function. Resources can also be converted into actions or other more valuable resources. Resources are typically used or consumed by paying for actions through budgeted action points, which is a way of letting players perform a trade-off analysis to decide from turn to turn which actions they want to perform. (For example, expending time and worker units to get to a resource tile in a turn-based strategy game to gain additional resources from the resource tile.) Resources are also consumed when they become part of objects built through Construction actions, or become destroyed due to
Regardless of how players achieve the resources they require, the players may start with Non-Renewable Resources to promote players externally beyond the confines of the Game Environment games and Betting (e.g. Money) in Casino games. In certain games the resources available at the beginning of game play Distribution or Asymmetric Resource Distribution to enforce different "War" or resources that can only be detected by Privileged Abilities [3]. Goals that give resources as rewards are in most games, where the player is required to select from a pool of characters with varying abilities, characters that have an unequal distribution of character attributes are usually complemented with handicaps.)

Goals are of equal importance in games, as players and agents in a Game World are required to make use of resources efficiently in order to achieve goals [3]. Goals that give resources as rewards are in most cases supporting goals. In addition to completing goals and collecting resources, players and agents may be able to redistribute resources among themselves. This adds additional difficulty to the modelling of resources for games as the distribution of resources among human players externally beyond the confines of the Game Environment cannot be accurately modelled in a game.

In certain games the resources available at the beginning of game play may be the only resources that exist while in other games resources might be renewable. In the latter case, they may be produced from Resource Generators that hand out resources at regular time intervals, or they may be Rewards for completing goals. These options are examples of Producer-Consumer resource control that involve Producers that create resources and Consumers that consume resources [3]. When the resources are collected from the Game World, several additional design choices are required, including the location of the resources, who can see them, and whether there are clues to where they can be found.

Secret Resources are resources that are either hidden by a "Fog of War" or resources that can only be detected by Privileged Abilities [3]. (For example, Privileged Ability units can be found in real-time strategy games that provide stealth units that can only be detected by special advanced radar units). Rewards can also be given for finding items that have been hidden. It is important to note that resources can be made to appear in different amounts or concentrations. As pointed out in an earlier example, time can also be a determining factor in the collection of resources.

As decisions have to be made regarding the interaction between the Game Element, the possession of resources can be made to affect Game Element characteristics [3]. The conversion of resources between physical and virtual can also be made possible. Players can also be empowered to have influence over how resources are distributed between players through player-decided resource distribution techniques. This can be done in conjunction with rewards and penalties.

Once possession of a resource is achieved, resources can be made to be stored in Containers, and limits can be imposed on the maximum number of resources that can be stored. Expiration limits can be imposed on the use of resources while penalties can be used to cause a loss in resources.

Resource Control can be decided in one of several ways. Players and Agents can be made to negotiate the use of Shared Resources or they can be allowed to manipulate the use of resources, although only indirectly. The Ownership of resources is another important factor as there is the option to make ownership changeable. The transfer of Control of resources involves a change in ownership and can be done by stealing and hand-overs. Players and agents can also be allowed to change resources through Trading. When resources are contested for and required to produce in-game units, the struggle for resources can turn into dilemmas where gaining control over larger amounts of resources can only be achieved by consuming larger amounts of resources.

The Strategic knowledge of a game can include knowing when to convert resources from one form to another. The conversion can also be made to have inefficient exchange rates (e.g. by making use of Diminishing Returns) or it can be made to require access to a Converter. Conversion of resources can also be made to be only possible through trading with other players or agents.

Scores can be regarded as a resource that is used to determine the winner of a game, while units can be considered common resources in games where the player assumes the role of god (e.g. "Black & White" from Electronic Arts). Resources provide players and agents with quantifiable measures to judge their progress and plan possible future actions. The resources can either exist from the beginning of game play or it may be created through Producers, and are either destroyed by Consumers, transformed through Converters, or are part of Closed Economies. Games where the goal consists of collecting various types of resources can use the number of owned resources as a score. In games that have a separate score system, resources are often used as a second order score system to function as tiebreakers. Resources are often also used to give Characters acting as Consumers or Converters the ability to perform actions. The presence of resources in Game Worlds can motivate Area Control goals and Exploration goals in the case of Secret Resources.

The relationship between the various resources and the control of these resources are Game Design issues that need to be handled through proper modelling. Making use of extensive rules to determine the various operations that are permitted on resources can be time consuming and error prone.

### 3. Secret Resources

Secret Resources are resources that are unknown to at least some of the players. There are two basic types of Secret Resources in games[3]. The first type governs what kind of information about the resources is available to one of the players and the second type governs situations where different players have different information available about resources.

Secret Resources are an outcome of the use of Imperfect Information, Uncertain Information and/or Asymmetric Information with resources. Imperfect Information when used with resources, will determine the availability of initial or current resources for a Game Element. Uncertainty of Information modulates the reliability of information
regarding available resources while Asymmetric Information determines the completeness of information available regarding each resource.

As resources determine the actions and strategies available to the players, Secret Resources have a direct impact on the players' ability to plan ahead, thus giving rise to Limited Planning Abilities for Game Elements [3]. The wish to know what resources exist in games, and how they are distributed, gives rise to Information Gain goals such as Reconnaissance or Exploration when Secret Resources are placed in a Game World.

A Secret Resource can be modelled after the events that it handles; actions that it produces; the set of valid states that it can possibly be in; and the state transition functions that define its transition from one state to another. The state of a Secret Resource can be said to change to another valid state when given either a partial or complete set of inputs that is denoted by the Monoid, $M_{R_{\text{secret}}}$.

$$\Phi_{R_{\text{secret}}} S_{R_{\text{secret}}} \times M_{R_{\text{secret}}} \rightarrow S_{R_{\text{secret}}}$$

A single state transition can be denoted in the following simplistic notation, where $m$ can represent a single input or a partial set of inputs, and $s$ denotes a particular state of the secret resource:

$$s_{R_{\text{secret}}} \times m \rightarrow s'_{R_{\text{secret}}}$$

Game Elements that instantiate a Secret Resource do so by sending event-based messages to Secret Resources. The information in input events received can either be utilised in full or partially, or be discarded. In either case, the entire set of input events is best represented by the above mentioned monoid $M_{R_{\text{secret}}}$. The sequence of events received is also important. Events received by a Game Object in the architecture are queued in an input buffer in the Event Handler of the Game Object. As events are sequentially retrieved, the order in which they were received by the Game Object is preserved. The Clock in the Scheduler of the architecture issues periodic events (of which intervals are pre-determined by the user) to signal the Event Handlers of each Game Object to empty and process the input buffers. In the case where the Event Handler cannot determine the actions to perform in response to an input set of events, it will insert the events back into the queue and discard them if they have not been processed before the event's expiry period. The sequence of events received is important because the Event Handler will decide to invoke the appropriate state transition function based on the set of events available at a particular point in time. However, as each state transition function will alter the state of the Game Element, cases where more than one possible state transition function can be invoked will have to be handled very carefully. This is because after a state change the option to invoke other alternative transition functions might no longer be available due to the constraints of the new state. For this reason, it is essential to analyse the set of possible inputs and determine as much as possible the minimum number of states required to represent a functional Game Element. However, as the implementation of resource and resource management in different genres of games varies, it is not possible to derive a single state machine that can be used by each and every game.

In an event-based architecture, it is necessary to differentiate between frequently occurring state transitions and transitions that do not occur as frequently. In games, there are many actions that occur frequently but do not significantly alter the state of a Game Object. In a turn-based strategy game, for example, this can be in the form of moving from one tile to another. Actions that require a significant and noticeable change in state can happen in a turn-based strategy when two players engage in battle. Although the change of state occurs internally, it is more useful to look at the Game Element, in this case a Shared Resource such as a black box system, and model the input events and actions that are the cause and result of a significant or insignificant change in state. Also, frequent state changes are associated with actions in low-level actions and AI routines. High-Level AI techniques normally produce a more significant change in state. Frequent state changes are best modelled with recurring state transition functions that change the state of an object back to the same general state after modifying some attributes. This greatly simplifies the model of the state machine for the Game Object. The two types of state changes will be differentiating between their associated events and actions by labelling them as "instantiates" and "modulates" respectively. Instantiating events cause significant changes in state, while modulating events cause less significant changes in state. Figure 2 shows a diagrammatic representation of all Game Elements that instantiate and modulate a Secret Resource and all Game Elements that a Shared Resource instantiates or modulates.

![Figure 2: Secret Resources](image)

The following Game Elements instantiate Secret Resources:

- **Initial Resource**, $R_{\text{initial}}$ - Initial Resource refers to the state of the resources that were initially allocated at the start of the game. Initial Resources are determined at the start of the game and they determine the availability of resources at load time.
- **Imperfect Information**, $W_{\text{Information}} \times U(I)$ - Imperfect Information refers to the composite state of incomplete information that is available for the discovery of resources. In this model, Imperfect Information is represented by a completeness manipulator, $W_{\text{Information}}$, and a factor $U$ that represents the uncertainty of the information.
- **Asymmetric Information**, $I_{\text{Asymmetric}}$ - Asymmetric Information refers to asymmetric information sources, where different information is available for different information sources.
- **Uncertainty of Information**, $U(I)$ - Uncertainty of Information refers to an input that modulates the uncertainty of information that is passed to the Shared Resource.

The Game Elements that modulate Secret Resources are the following:
Reconnaissance, $S_{\text{reconnaissance}}$ - Reconnaissance refers to the Game Element that performs the action of searching and surveying in the Game Environment. The discovery of secret resources will convert the resources discovered into other resources. However, the state of Secret Resource does not need to change as only the portion of resources that have been discovered are affected.

Cumulatively, a change in state would be a result of the inputs defined by the following monoid:

$$M_{\text{Shared}} = \{m(R_{\text{initial}}), m(U \times W(I_{\text{asymmetric}})), m(S_{\text{reconnaissance}})\}$$

The change in state of Secret Resources will either modulate or instantiate a number of other Game Elements. The Game Elements that Secret Resources instantiate are the following:

- **Exploration, $S$** - Exploration refers to the Game Element that controls an in-game unit’s exploration search pattern.
- **Gain Information, $I_{\text{gain}}$** - Gain Information refers to the Game Element that increases the amount of useful information in a Game Object.

**Limited Planning Ability, $W(P_{\text{limited}}) - P_{\text{limited}}$** refers to the planning ability of an intelligent unit in the game, while $W$ is a factor that moderates the planning ability of the unit.

The Game Elements that Secret Resources modulate are the following:

**Basic Resources, $R_{\text{basic}}$** - Basic Resources refers to the basic set of resources that are present in a game.

**Game World, $ENV$** - Game World refers to the model of the Game Environment. This includes the attributes and properties within the Game Environment, and may also include configurable constraints.

4. **Limited Resources**

Limited Resources are introduced to make it possible for some resources to run out during game play. The resources available to the players can be limited to such an extent that players and AI agents are forced to plan ahead the use of the resources available to them [3].

There exist a number of games that use resources to provide the Right Level of Challenge in games. In such games the availability of resources is restricted. This means that players and AI agents in the game have Limited Resources in some sense and have to make use of them in the most efficient way to play the game as well as possible.

Limited Resources can be used together with both Non-Renewable Resources and Renewable Resources [3]. The commonality in both cases is the need to control the amount of resources available to the player or agent at any point of game play in such a way that the player is always forced to plan and to make tradeoffs when using the resources. This is often done by having some form of Container that limits the amount of resources available. The capacity of the Container, in turn, can be modulated by Improved Abilities or Decreased Abilities. Limited Resources and Renewable Resources can be combined in different ways to introduce meaningful game play mechanics. For example, Pick-Ups or Resource Generators can be used to replenish resources that have been consumed so that the initial resource constraints imposed by Limited Resources can be offset later in the game through other Renewable Resources [3]. However, this requires that either the resource must be used at a much later stage or that the amount of Renewable Resources is limited. Limited Resources can be used, for example, through Time Limits or Budgeted Action Points, to lessen Downtime and potential imbalances between players in games that are based on Turn Taking (e.g. Turn based Strategy Games, such as Sid Meier’s “Civilization 4”).

Limited Resources decrease players’ Freedom of Choice. In principle all games have Limited Resources, but often some of the resources are more limited than others, forcing the player to plan and form strategies about the use of these resources. The amount of available resources limits the possible actions and strategies of the players, and thereby their Freedom of Choice. Limiting the amount of resources available to the player reduces the potential actions possible for the player and increases the level of Stimulated Planning required. Planning how to use Limited Resources is one of the corner stones of Resource Management and having skills in making the most use of Limited Resources is advantageous in Risk Assessment.

**Figure 3: Limited Resources**

The Game Elements that instantiate Limited Resources are the following:

**Time Limit, $T_{\text{time}}$** - Time Limit refers to a Game Element that imposes a time limit on a certain action performed on Limited Resources.

**Budgeted Action Points, $B \times P_{\text{Action}} - P_{\text{Action}}$** refers to a point system that is used to numerically represent the availability and usage characteristics of resources. Budgeted Action Points will then be the point system that modulates the availability of resources.

**Non-Renewable Resources, $R_{\text{non-renewable}}$** - Non-Renewable Resources refers to a resource Game Element that possesses resources that cannot replenish themselves throughout the entire game play.

**Containers, $C_{\text{container}}$** - Containers refers to a resource control element that is designed to store other resources.

The Game Elements that modulate Limited Resources are the following:

**Decreased Abilities, $D(A)$** - Decreased Abilities refers to a game element that modifies and reduces the attributes of Limited Resources.

**Improved Abilities, $I(A)$** - Improved Abilities refers to a Game Element that modifies and increases the attributes of Limited Resources.

**Renewable Resource, $R_{\text{renewable}}$** - Renewable Resource refers to resources that are renewable and can modify the
amount of Limited Resources available after resources have been consumed.

The inputs that cause a change in state in a Limited Resource will be the result of the monoid, defined as follows:

\[ M_{\text{Limited}} : \{ m(C_{\text{Container}} \times R_{\text{Non-Renewable}}), m(B \times P_{\text{Action}}), m(I(D((A))), m(T_{\text{Limit}}) \} \]

The change in state of Limited Resources will either modulate or instantiate a number of other Game Elements. The Game Elements that Limited Resources instantiate are the following:

**Resource Management, \( C_{\text{Management}} \)** – Resource Management refers to a Game Element that manages and monitors the allocation of resources. In the case of the proposed Game Architecture, this is implemented as an Overseer.

**Game Mastery, \( A_{\text{Mastery}} \)** – Game Mastery refers to a Game Element that modifies the skill level of an agent or human player.

**Risk Assessment, \( S_{\text{Risk-Assessment}} \)** – Risk Assessment refers to the Game Element that performs risk analysis by searching through the possibility space of actions and determining an action that maximises rewards and reduces risks.

**Decreased Abilities, \( D(A) \)** – Decreased Abilities refers to a factor that manipulates and reduces the attributes that determine a Game Element’s abilities.

The Game Elements that Limited Resources modulate are the following:

**Tradeoffs, \( C_{\text{Tradeoffs}} \)** – Tradeoffs refers to a resource control mechanism that determines the tradeoffs that need to be made in obtaining resources. Tradeoffs can be in the form of consuming action points to gain resources.

**Freedom of Choice, \( P_{\text{Freedom}} \)** – Freedom of Choice refers to an element that caches the possibility space of actions that can be taken by a Game Element.

**Down-Time, \( T_{\text{Down-Time}} \)** – Down-Time refers to an element that prevents a Game Element from performing actions for a period of time.

**Pickups, \( R_{\text{Pickups}} \)** – Pickups refers to an action that a player or agent can perform on a resource.

**Stimulated Planning, \( P_{\text{Stimulated}} \)** – Stimulated Planning refers to an intelligent Game Element that can manage game play in such a way that it is able to stimulate the AI agents and human players to perform advanced and future planning before performing any actions.

**Resources Generators, \( G_{\text{Resources}}(R) \)** – Resources Generators refers to Game Elements that can produce and replenish resources in the Game World.

**Resources, \( R \)** – Resources refers to the set of all resources available in the game.

### 5. Non-Renewable Resources

Non-renewable resources have a fixed amount of resources available from the start to the end of the game, game session, play session or mode of play [3]. These resources cannot be renewed once they are exhausted. These Non-Renewable Resources thereby have a fundamentally higher value than resources that are replenished, and the use of Non-Renewable Resources is a greater commitment than the use of other resources.

Non-Renewable Resources can be used in two main ways based on the Ownership of the Resources or Units [3]. The first option is to give each of the players a certain amount of Non-Renewable Resources. Modification of the amount available to the players can be used to achieve Player Balance through providing a Handicap. The other option is to make the resources non-renewable from the game system point of view, but give the players the possibility of replenishing their resources.

The best way to impose a Time Limit on the game instance or game sessions is to make the resources used in the players’ basic actions non-renewable. The loss of these resources can then be used as an end condition of either the whole game instance or just the player’s game session. The game can, of course, contain both Renewable and Non-Renewable Resources, if they are different resources or if the Ownership of the Resource has an effect on the status of the resource.

Non-Renewable Resources are a natural way to impose a Time Limit on game instances as players’ actions exhaust the resources [3]. They also create Higher-level closures as game play progresses since the value of resources increases with their rarity as long as the functionality they provide is at least as important in late game play as in earlier game play. Non-Renewable Resources are also automatically Limited Resources. Non-Renewable Resources that are part of Closed Economies may be perceived as being Renewable Resources by the players although it is actually the same resources which are recycled.

Non-Renewable Resources that are consumed by actions make experimenting costly in games, and promote solution finding activities that require abstract reasoning [3]. The use of depletion of Non-Renewable Resources as end conditions for goals or games can also be used as an end condition.

![Figure 4: Non-Renewable Resources](image-url)

The Game Elements that instantiate Non-Renewable Resources are the following:

**Initial Resources, \( R_{\text{Initial}} \)** - Initial Resources refer to the initial allocation of resources within the Game Environment.

**Budgeted Action Points, \( B \times P_{\text{Action}} \)** - Budgeted Action Points refers to a point system where all actions are modelled to either consume or produce a certain number of...
points. The player will then have to take into consideration the point consumption and production rate of these actions and make a well-informed decision on the action to take.

**Non-Renewable Resources**, $R_{\text{Non-Renewable}}$ - Non-Renewable Resources refers to a resource Game Element that possesses resources that cannot replenish themselves throughout the entire game play.

**Container**, $C_{\text{Container}}$ - Container refers to a resource control element that is designed to store other resources.

The Game Elements that modulate Non-Renewable Resources are the following:

- **Transfer of Control**, $C_{\text{Transfer}}$ - The transfer of control modifier transfers the control of a game element from one entity to another.
- **Ownership**, $C_{\text{Ownership}}$ - The ownership modifier assigns the ownership of a resource from one Game Entity to another.
- **Higher-level Closures**, $C_{\text{Closure}}$ - High-level Closure Controllers ensure that state changes in Game Elements maintain a valid Game State.

The change in state of Limited Resources will either modulate or instantiate a number of other Game Elements. The Game Elements that Non-Renewable Resources instantiate are the following:

- **Closed Economics**, $C_{\text{ClosedEconomics}}$ - The Closed Economics Resource Controller ensures that the amount of available resources is constant. This is possible as resources can be of a number of different types and a points system can be used to create equivalent resources from destroyed resources at a later time.
- **Decreased Abilities**, $D(A)$ - Decreased Abilities refers to a game element that modifies and reduces the attributes of Limited Resources.

The Game Elements that Non-Renewable Resources modulate are the following:

- **Units**, $GE_{\text{Unit}}$ - Units refer to Game Elements in the game world that can be assigned to players.
- **Player Balance**, $M_{\text{PlayerBalance}}$ - Player Balance refers to a game element that regulates the allocation of resources so that each player will have a balanced allocation of resources.
- **Resources**, $R$ - Resources refer to the set of all resources available in the game.
- **Handicaps**, $M_{\text{Handicap}}$ - Handicaps refers to a game element that modifies the resource allocation in another game element by limiting the abilities of the game element.
- **Puzzle Solving**, $S_{\text{Puzzle}}$ - Puzzle Solving refers to an element that makes use of puzzle solving to handle the allocation of resources.
- **Randomness**, $M_{\text{Randomness}}$ - A randomness modifier introduces randomness to the resource allocation process of a resource.
- **Limited Resources**, $R_{\text{Limited}}$ - Limited Resources refer to resources that may run out during the game.

## 6. Renewable Resources

Resources that players use in games may be replenished by regaining the original resources or receiving replacements and are called Renewable Resources [3]. Renewable Resources can exist at several levels in the same game. Resources that the players perceive to be renewable might not be renewable from the game system's point of view, i.e. there may be a hidden limit on the availability of resources in the game system.

Renewable Resources are created through the use of Chargers, Converters and Closed Economies and can be modulated by the placement of Resource Generators, and Time Limits on when resources can be renewed [3]. In the case of Converters the resources may not be renewable from a game system's perspective but may be so from the players' perspectives, since Closed Economies and Resource Generators can guarantee Renewable Resources even if players may not be aware of the possibility of replenishing used resources. Similarly, the number of Pick-Ups and the effect of Chargers may be limited in the game but can appear to provide Renewable Resources from the players' perspective.

Renewable Resources are always associated with a renewal rate [3]. It is usually easier to calculate, modify and balance the renewal rate from the game system's point of view but it is as important to try to calculate the renewal rate from the players' perspective also.

Renewable Resources are always associated with Producers that govern the direct renewal rate of the resources [3]. This renewal rate can be static during the whole game; it can be controlled by the players; or it can change according to the game state. When the Renewable Resources are produced by Controllers, Units or Characters under the players' control, the rate of renewal is usually limited by requiring another form of resource; or by having Time Limits on how often the actions can be used; or by using Budgeted Action Points. The ability of Units or Characters to produce in-game resources are often considered Privileged Abilities.

One interesting way of using changes in the renewal rate is to allow the players to overuse the resources without direct Penalties, but where the overuse decreases the renewal rate steadily and permanently [3].

The container is limited in what it can accommodate in resources. This is intuitive in the case of, for example, the health of the players' Characters or Units. A slightly more unintuitive use of a Container with Renewable resources is the use of Budgeted Action Points where the Container, together with the renewal rate, dictates how many action points are available to a player.

Renewable resources can be used to give the players meaningful subgoals or Closure within a Hierarchy of Goals in the game as the players also have to struggle to Gain Ownership of the Resources during the game. Players may have Reconnaissance goals when the resources are renewed but players do not necessarily need to know where or when they are renewed.

The second common case of Renewable Resources is with Resource Management when players have Ownership of Producers generating the resources and the players' task is to maximise the benefit of these basic resources. In these cases the renewal rate of the Renewable Resource is, in fact, the Limited Resource the players have to manage.
Lives refer to the number of lives a player has. The number of lives a player has can alternatively be modelled by, \( R_{\text{Lives}} \times G \times n \), where \( n \) is the number of lives.

**Controller**, \( G(\tau) \) - Resource Controllers control the allocation and distribution of resources within the game.

**Diminishing Returns**, \( D(P_{\text{Returns}}) \) - Diminishing returns make use of a point system to constantly reduce the resources gained by repeatedly performing the same action.

**Time Limit**, \( T_{\text{Limit}} \) - Time limit refers to a Game Element that imposes a time limit on a certain action on Limited Resources.

The inputs to Renewable Resources are best described as by the following monoid:

\[
M_{\text{Renewable}} = \{ m(C_{\text{Ownership}} \times C_{\text{Asymmetric}} \times C_{\text{Distribution}} \times C_{\text{Converters}} \times C_{\text{ClosedEcononies}} \times G(R_{\text{Non-Renewable}} \times R_{\text{Pick-Ups}}))
, m(T_{\text{Limit}}), m(D(P_{\text{Returns}})), m(B \times P_{\text{Action}}) \}
\]

The Game Elements that Renewable Resources instantiate are the following:

**Reconnaissance**, \( S_{\text{Reconnaissance}} \) - Reconnaissance is a search strategy that is used to gain more information.

**Privileged Abilities**, \( P_{\text{Privilege}} \) - Privileged Abilities are special abilities that can only be accessed once a Game Unit has acquired an adequate quantity of a certain resource.

**Tradeoffs**, \( C_{\text{Tradeoffs}} \) - Tradeoffs refer to a resource control mechanism that determines the tradeoffs that need to be made in obtaining resources. Tradeoffs can be in the form of consuming action points to gain resources.

The Game Elements that Renewable Resources modulate are the following:

**Chargers**, \( C_d \) - Chargers refer to resource generators that are able to generate more resources given appropriate Resource Container types.

**Damage**, \( A_{\text{Damage}} \) - Damage refers to an ability in a Game Element to reduce the resources owned by another Game Element. Typically, it reduces the health of another game unit.

**Units**, \( G_{\text{Units}} \) - Units refer to Game Elements in the game world that can be assigned to players.

**Resources**, \( R \) - Resources refer to the set of all resources available in the game.

**Lives**, \( R_{\text{Lives}} \) - Lives refer to the number of lives a player has. The number of lives a player has can alternatively be modelled by, \( R_{\text{Lives}} \times G \times n \), where \( n \) is the number of lives.

**Characters**, \( G_{\text{Characters}} \) - In-game characters can also be modelled as Units. As all units are distinguished by their abilities, there is no need to differentiate between different game elements.

**Transfer of Control**, \( C_{\text{Transfer}} \) - The transfer of control modifier transfers the control of a game element from one entity to another.

**Ownership Gain**, \( I \times C_{\text{Ownership}} \) - The ownership modifier causes a Game Element to relinquish a resource and assigns the ownership of the resource to another Game Entity.

**Limited Resources**, \( R_{\text{Limited}} \) - Limited Resources refer to resources that may run out during the game.

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**Figure 5: Renewable Resources**

The Game Elements that modulate Renewable Resources are the following:

**Chargers**, \( G_d(\tau) \) - Chargers refer to resource generators that are able to generate more resources given appropriate Resource Container types.

**Closed Economics**, \( C_{\text{ClosedEconomics}} \) - The Closed Economics Resource Controller ensures that the amount of available resources is constant. This is possible as resources can be of a number of different types and a points system can be used to create equivalent resources from destroyed resources at a later time.

**Budgeted Action Points**, \( B \times P_{\text{Action}} \) - \( P_{\text{Action}} \) refers to a points system that is used to numerically represent the availability and usage characteristics of resources. Budgeted Action Points represent a points system that modulates the availability of resources.

**Resource Generators**, \( G_{\text{Resources}}(\tau) \) - Resource Generators refer to Game Elements that can produce and replenish resources in the Game World.

**Producers**, \( G(\tau) \) - Producers refer to a Game Element that can produce other Game Elements.

The Game Elements that instantiate Renewable Resources are the following:

Pick-ups, \( R_{\text{Pick-Up}} \) - Pick-Up resources refer to a type of resource that exists in discrete unit quantities at predetermined or predictable locations in the Game World.

Converters, \( C_{\text{Converters}} \) - Converters refer to a resource modifier that converts resources from one type to another.

Asymmetric Resource Distribution, \( C_{\text{Asymmetric}} \times C_{\text{Distribution}} \) - Resource Distribution Controllers can generally be represented by \( C_{\text{Distribution}} \). The asymmetric resource controller is used for an asymmetric resource distribution strategy.

Ownership, \( C_{\text{Ownership}} \) - The ownership modifier assigns the ownership of a resource from one Game Entity to another.
7. Closed Economies

Closed Economies in games mean that there is no production of resources within the game system and that the resources do not leave the game system [3]. These resources, however, are free to circulate within the game system and can be transformed into other resources and Game Elements during game play.

Closed Economies are easier to create when the resources used during the game cannot be converted to other types of resources [3]. In these cases it is usually the distribution of these resources among the different players that is used as the main variation in game play.

Although the number of resources is fixed in Closed Economies, their distribution can vary and sometimes the possibility of variation is modulated by restricting the number of potential owners of the resources [3]. This in turn can be used as an end condition for game sessions. The players that run out of resources are then removed from play through Player Elimination.

More complex cases of Closed Economies are found in games where the resources can be converted to other types of resources through the use of Converters. If this conversion can be cyclical (i.e. where Resource A can be converted to Resource B, and later Resource B can be converted back to Resource A), the conversion rate has to be symmetrical [3]. In more complex cases, the number of resources may differ, but for the system to be a Closed Economy the original distribution of resources must be achieved, providing a form of reversibility even though other parts of the game state may have changed. The conversion of Initial Resources to other resources can also be used as an end condition for the game. This happens when all or a certain amount of the Initial Resources are converted, causing the game or the mode of play to end.

Closed Economies make the use of resources independent of the number of resources in a game. This makes them into Renewable Resources from the players’ perspective although they are Non-Renewable Resources from the Game Designer’s perspective.

Games with Closed Economies usually impose a kind of Time Limit to game instances as Closed Economies can easily grind to a halt, either when the resource distribution among the players becomes unbalanced or when there are no further favourable possibilities for converting the available resources.

The Game Elements that instantiate Closed Economies are the following:

- **Transfer of Control, C_{Transfer}** - The transfer of control modifier transfers the control of a game element from one entity to another.
- **Non-Renewable Resources, R_{Non-Renewable}** - Non-Renewable Resources refer to a Game Element that possesses resources that cannot replenish themselves throughout the entire game play.
- **Resource Control, C_{Resource}** - Resource Controllers control the allocation and distribution of resources within the game.

The change in the state of Limited Resource will either modulate or instantiate a number of other Game Elements. The Game Elements that Closed Economies instantiate are as follows:

- **Player Elimination, C_{Elimination} (x R_{Low})** - The concept of killing units in games is common to most games. It can be represented as a resource control mechanism that eliminates a resource.
- **Renewable Resource, R_{Renewable}** - Renewable Resource refers to resources that are renewable and that can modify the amount of Limited Resources available after resources have been consumed.

The only Game Element that Closed Economies modulate is as follows:

- **Resources, R** - Resources refer to the set of all resources available in the game.

8. Conclusions

This paper reviews the resources as items used in support of some activity that needs to be drawn from an available supply of resources. The management of these resources significantly contributes to the experience involved in playing a game. Our contribution in this paper is to extend what we have reviewed from the literature on the game resources. We mapped the nature of the resources to states and state transition functions. With the states and state transition functions from this paper, it will enable future work to construct an efficient modelling framework to examine resource control and management for MMOG.

9. REFERENCES