How to clean up space debris – using game theory

November 13 2015, by Karl Tuyls

Credit: ESA/Spacejunk3D, LLC

A piece of debris just 10cm in diameter could cause an entire spacecraft to disintegrate and it is estimated that there are more than 29,000 objects larger than 10cm in Earth's orbit. This poses a major risk to the spacecraft to-ing and fro-ing from the International Space Station, not to mention the hundreds of satellites that are now essential to daily lives.

Although there are many organisations that could be seriously affected by space debris, including most governments and many businesses, so far no one has taken any serious action to tackle the problem. But by using the mathematical modelling of game theory, my colleagues and I hope to devise a strategy to encourage these players to act to avoid the kind of disaster that a major space debris collision could cause.

National space agencies and private satellite and communications companies all have an interest in reducing the amount of debris in orbit. If one organisation attempts to remove debris it will benefit everyone operating in space. But because doing so will be complex and very costly, the apparent best option for any one of these players is to wait for somebody else to have a go first. That would give them a cleaner space to operate in without the expense of clearing it up themselves.

The problem, of course, is that if everyone thinks like this, then the amount of debris will just keep increasing. Ageing satellites and used rocket launchers are creating new debris all the time, while the total number of fragments goes up every time two pieces collide and break into even smaller pieces. The build-up of space debris in this way could eventually result in a catastrophic cascade of collisions known as the Kessler syndrome. (You may have seen the possible effects of this in the film Gravity.)

This dilemma of whether to accept the cost of acting or risk disaster by waiting is the kind of strategic problem studied by game theory. A situation like the space debris problem, where players act just for their own benefit instead of taking group interests into account, is referred to in game theory as the "tragedy of the commons". As a result, a shared resource (in this case, space and low-earth orbit) is over-used by all individuals and is no longer useful to anyone, leading to higher costs for everyone involved.

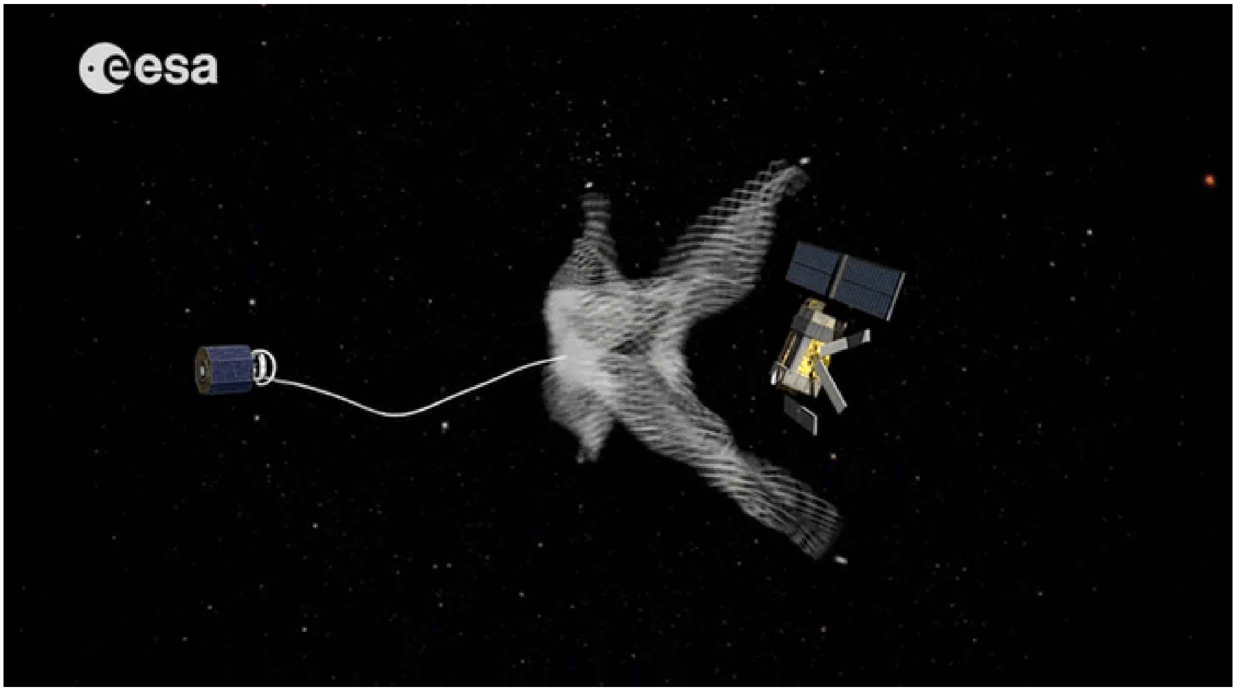
Game theory comes from economics and studies the interactions and strategic decision-making of several entities. These entities can be individuals, organisations, governments and even intelligent or automated computer programs ("agents").

In computer science, techniques from game theory are popular in research into artificial intelligence and multi-agent systems because they can help design software to analyse strategic situations and take good decisions without human supervision. For example, it can help design an agent to take part in an auction for you, instantly bidding or negotiating for commodities to get the best possible deal.

In game theory, strategic situations are classically modelled as a game featuring several players that each have a choice of several actions. They choose which action to take based on their own preferences and the behaviour of their opponents. The outcome for each player then depends on the choices of everyone in the game. A famous example is the prisoner's dilemma game, in which two criminals receive different sentences depending on whether they cooperate with the authorities and give evidence against their accomplice.

Classical game theory tells you how to act in situations like the prisoner's dilemma to achieve the best outcome. One the most important elements of the theory is the Nash equilibrium concept. This means that players are assumed to be perfectly logical and behave rationally. Interestingly, it seems that when players take the most rational decisions it does not always lead to cooperative behaviour or the best outcomes.

For our space debris dilemma, more recent versions of game theory, such as dynamic game theory and evolutionary game theory, are particularly useful because they can deal with changing circumstances. For instance, evolutionary game theory assumes that the players aren't fully rational but are also socially and biologically conditioned. This provides a better way of describing the behaviour of social human beings or, on a bigger scale, multinational organisations.



Catch the satellite. Credit: ESA

Space game

We aim to create a realistic computer model of debris removal situations that can be used to perform an analysis using game theory. This should be able to explain the different ways entities involved in space debris build-up behave. For example, it could predict the amount of effort each entity would be willing to invest on clean-up given the immediate and long-term risk to their space assets such as satellites.

This will then enable us to better understand how different debris removal strategies might work and determine the best ones for different players to take. For example, each player could commit to removing one piece of debris each year, or a number of pieces proportionate to the number of new satellites the player launches. Game theory can basically tell us whether we can expect such strategies to result from the self-interested interaction between the parties involved.

The final result should be a mechanism to "steer" the situation and create incentives to encourage the self-interested players to take actions that won't lead to the tragedy of the commons. For example, internationally agreed taxes or fines could make removing or preventing the growth of space debris in the immediate best interests of certain players. Without such action, the mess we're creating in orbit is only likely to get worse.

Source: The Conversation

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