Case Study - Hypothetical Immunological Response Model Graph Transformation Rules

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1 Introduction

This report accompanies current research on membrane-inspired graph transformation systems. Contained within are details of a hypothetical model of cellular viral infection and subsequent immunological response for some imagined multicellular organism. Section 2 presents the graph transformation rules in a concrete model (after the addition of *aggregating attributes*) detailing the complete behaviour of the system. Section 3 shows the remaining rules after the concrete model has been abstracted. Rules that have become identity rules are removed from the abstract model and are not shown.

Rule name abbreviations that have been used in some work are given after each rule name.

2 Concrete Model Rules

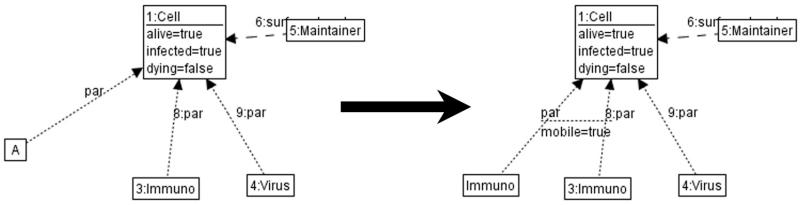

Fig. 1. Immuno creation (*IC*): The cell utilises auxiliary species *A* and replicates an existing *Immuno* when a *Virus* has invaded a living cell.

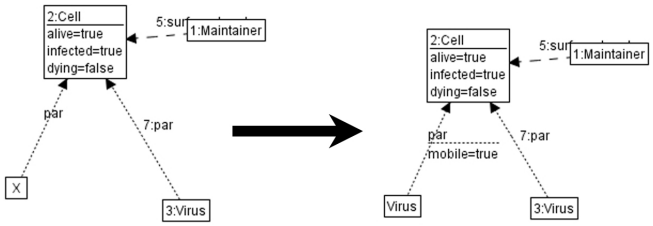

Fig. 2. Virus creation (*VC*): The *Virus* manipulates auxiliary species X to replicate itself within a living cell.

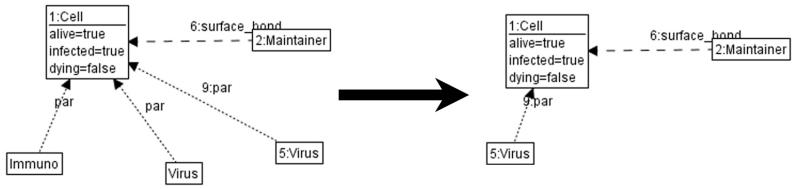

Fig. 3. Immunoresponse variation 1 (*IR1*): An *Immuno* eliminates a *Virus* within a cell.

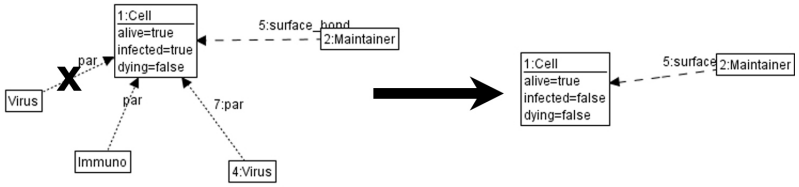

Fig. 4. Immunoresponse variation 2 (*IR2*): An *Immuno* eliminates the last *Virus* within a cell.

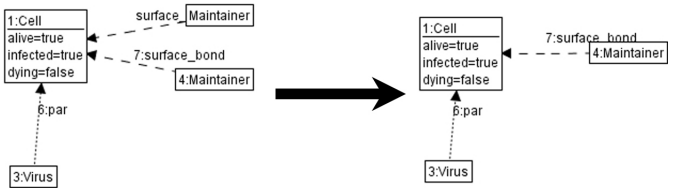

Fig. 5. Viral activity variation 1 (*VA1*): A *Virus* destroys a *Maintainer* bonded to the surface of a cell.

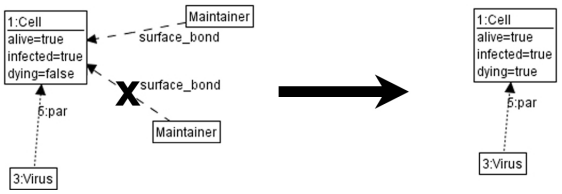

Fig. 6. Viral activity variation 2 (*VA2*): A *Virus* destroys the last *Maintainer* bonded to the surface of a cell, therefore initiating programmed cell death

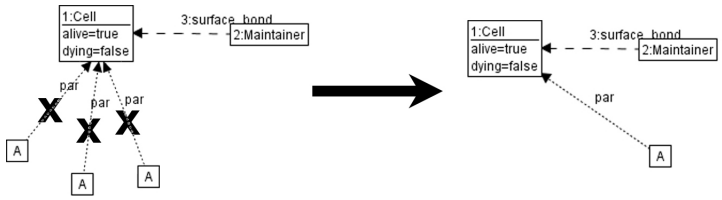

Fig. 7. *A* creation (*AC*): A living cell regenerates auxiliary species *A*, with an upper limit of 3 *A*'s per cell

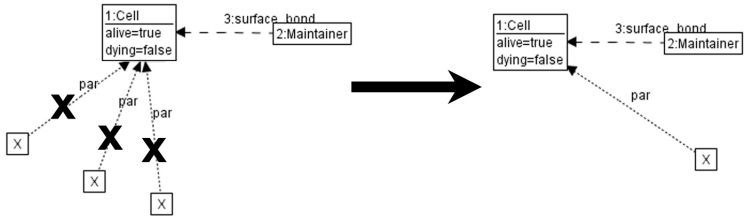

Fig. 8. *X* creation (*XC*): A living cell regenerates auxiliary species *X*, with an upper limit of 3 *X*'s per cell

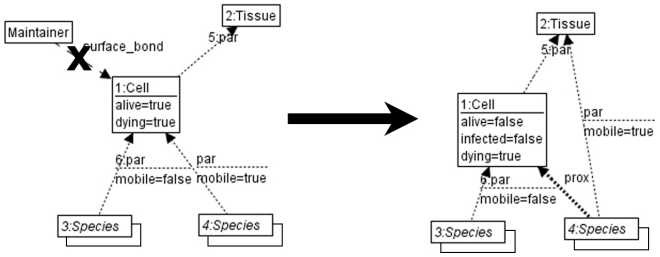

Fig. 9. Cell death (*CD*): A dying cell dissolves. Instead of deleting the cell, we keep its "ghost" for accounting purposes. The *Species* nodes in the cell are multiobjects [1]. Immobile species will dissolve, while mobile ones will be released into the area delimited by the tissue membrane.

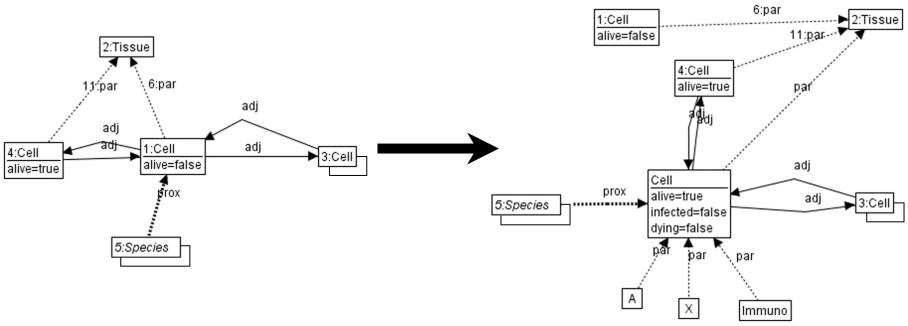

Fig. 10. Cell regeneration (*CR*): Given a gap in the cell structure, i.e., a dead cell, an adjacent living cell can replicate itself into the space. The new cell contains one *X*, one *A* and one *Immuno*, and inherits the old cell's *prox* and *adj* relations

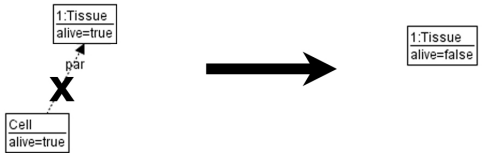

Fig. 11. Tissue death (*TD*): A tissue with containing no living cells dies.

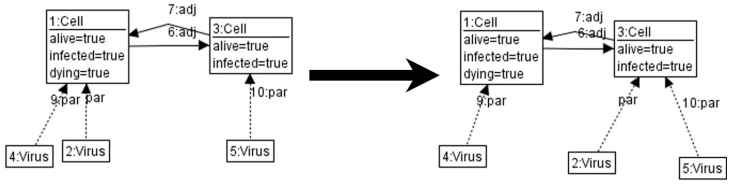

Fig. 12. Virus tunnelling variation 1 (*VT1*): A *Virus* tunnels from a dying cell to an adjacent cell. The infection state of both cells is unchanged.

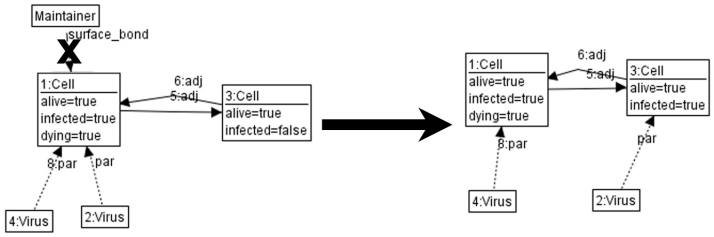

Fig. 13. Virus tunnelling variation 2 (*VT2*): A *Virus* tunnels from a dying cell to an adjacent cell. The infection state of the receiving cell is changed.

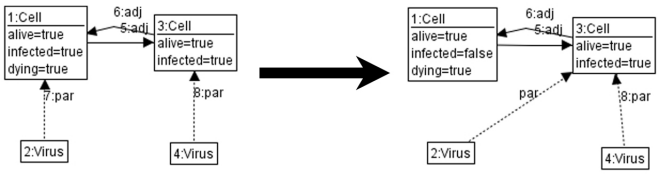

Fig. 14. Virus tunnelling variation 3 (*VT3*): A *Virus* tunnels from a dying cell to an adjacent cell. The infection state of the transmitting cell is changed.

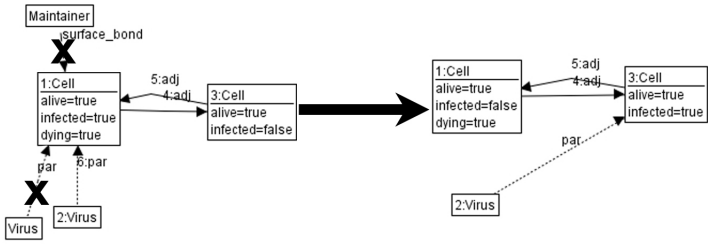

Fig. 15. Virus tunnelling variation 4 (*VT4*): A *Virus* tunnels from a dying cell to an adjacent cell. The infection state of both cells is changed.

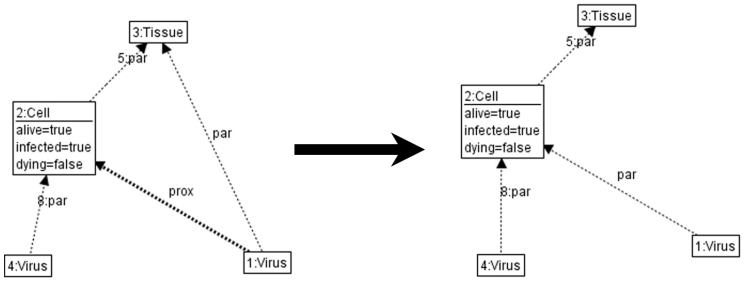

Fig. 16. Virus invasion variation 1 (*VM1*): A *Virus* enters a cell from the tissue membrane. The cell already contains virus(es) and its infection state is unchanged.

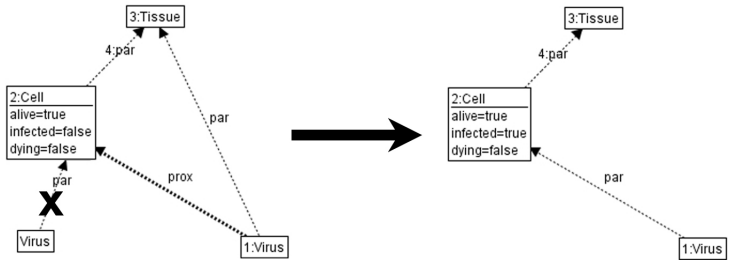

Fig. 17. Virus invasion variation 2 (*VM2*): A *Virus* enters a cell from the tissue membrane. The cell is previously clean and its infection state is changed.

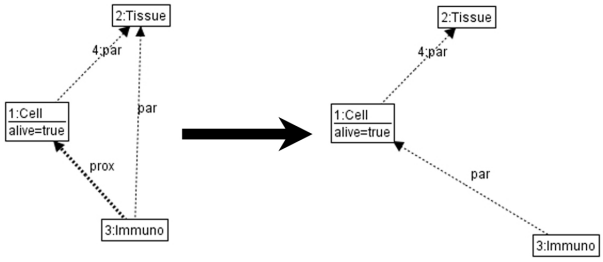

Fig. 18. Immuno migration (*IM*): An *Immuno* enters a cell from the tissue membrane.

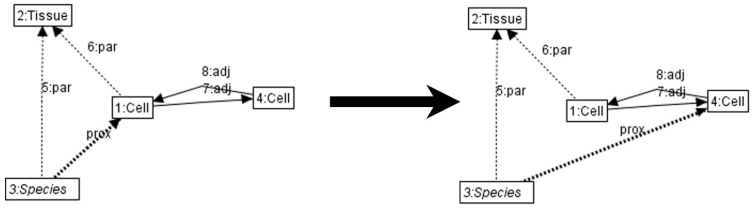

Fig. 19. Species movement (*SM*): A mobile *Species* can diffuse through the tissue when it is not within a cell. Movement is random over the cell structure and is tracked via its proximity to cell positions.

3 Abstract Model Rules

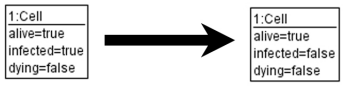

Fig. 20. Abstract immunoresponse variation 2 (*A_IR2*): An *Immuno* eliminates the last *Virus* within a cell, changing the cell's infection state

Fig. 21. Abstract viral activity variation 2 (*A_VA2*): A *Virus* destroys the last *Maintainer* bonded to the surface of a cell, therefore initiating programmed cell death

Fig. 22. Abstract cell death (*A_CD*): A dying cell dissolves. Instead of deleting the cell, we keep its "ghost" for accounting purposes. In the concrete model, viruses are returned to the tissue membrane when the cell dissolves. In the abstract model, since viruses are hidden within cells, we always return one virus to the tissue membrane. This number represents the modal number of viruses released and was determined by stochastic simulation experiments.

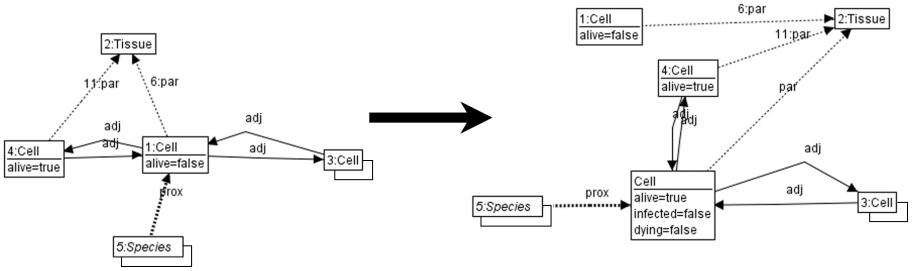

Fig. 23. Abstract cell regeneration (*A_CR*): Given a gap in the cell structure, i.e., a dead cell, an adjacent living cell can replicate itself into the space. The new cell contains one *X*, one *A* and one *Immuno*, and inherits the old cell's *prox* and *adj* relations

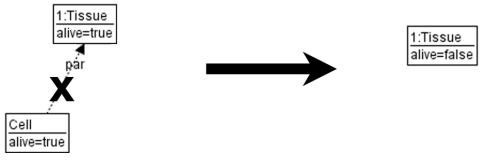

Fig. 24. Abstract tissue death (*A_TD*): A tissue with containing no living cells dies.

Fig. 25. Abstract virus tunnelling variation 2 (*A_VT2*): A *Virus* tunnels from a dying cell to an adjacent cell. The infection state of the receiving cell is changed. In the abstract model, we disregard the infection state of the transmitting cell. As such, only this variation of the rule remains.

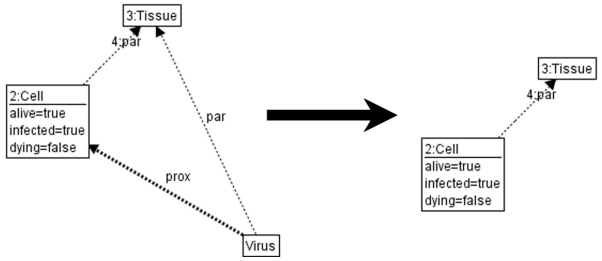

Fig. 26. Abstract virus invasion variation 1 (*A_VM1*): A *Virus* enters a cell from the tissue membrane. The cell is already infected and its infection state is unchanged.

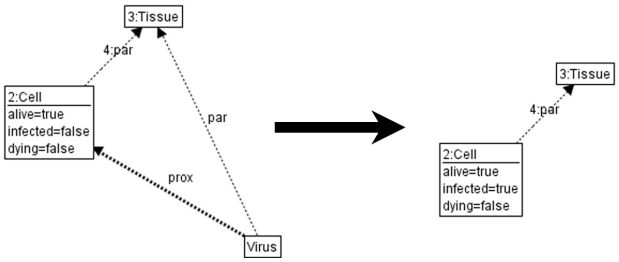

Fig. 27. Abstract virus invasion variation 2 (*A_VM2*): A *Virus* enters a cell from the tissue membrane. The cell is previously clean and its infection state is changed.

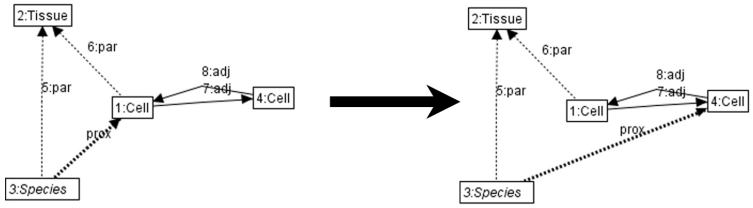

Fig. 28. Abstract Species movement (*A_SM*): A mobile *Species* can diffuse through the tissue when it is not within a cell. Movement is random over the cell structure and is tracked via its proximity to cell positions.

References

1. Heckel, R.: Graph transformation in a nutshell. Electronic Notes in Theoretical Computer Science 148(1), 187–198 (2006)