Parcel subdivision automation for agent-based land use modelling

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Abstract: To a significant extent rural Australia is transforming into multifunctional landscapes. Amenity migration (i.e. movement of people from metropolitan to rural settings) is a major driving force of this transition in many areas. However, the effects of amenity migration on the receiving landscapes are not yet fully understood. Agent-based land use modelling helps unravel the complex spatio-temporal relationships that affect landscape response to change from amenity migration. A land subdivision module is essential for a complete agent-based land use model developed for these landscapes because the land sold to in-migrants are lots that are subdivided from much larger tracts. In this paper we describe a land subdivision automation procedure and its implementation for a rectangular land system. It takes into account the dimensions of the candidate parcel, minimum lot size, and initial street arrangement for both target and neighbouring parcels. Subdivision layouts can be generated either to achieve the maximum number of lots or an optimal balance between number of lots and new streets. This module provides subdivision layouts for all candidate parcels in the land use model. And it potentially serves as an integral component in many other models, as well as a stand alone tool for generating subdivision layouts, complex polygon splitting and studies that attempt to establish relationships between land subdivision and habitat fragmentation.

Keywords: Agent-based land use model, amenity migration, land subdivision, rural land use

1. INTRODUCTION

Rural farmlands in Australia are ecologically, economically and socially important landscapes. It has been argued that Australian and other rural landscapes are increasingly undergoing a transition whereby diverse values displace, to spatially variable extents, formerly dominant production values (Holmes, 2006; Robbins et al 2009). The emergence of market-driven amenity values is a major driving force of this transition (Holmes, 2006). This occurs as a result of people moving from urban/metropolitan areas into accessible and/or high amenity rural areas seeking a lifestyle change (Burnley and Murphy, 2004; Costello, 2007). The movement of city dwellers into rural landscapes raises a suite of natural resource management and planning issues (Pini and Mckenzie, 2006; Gill et al in Press; Gosnell et al 2006). One thing that does appear certain, however, is that the transition leads to more heterogeneous and complex rural landscapes (Holmes, 2006).

Land use modelling makes an important contribution to understanding and managing these complex, coupled socio-ecological systems. An agent-based land use modelling approach can handle situations such as a heterogeneity of actors (land owners), the presence of dynamic interactions among actors and their environment (Loibl and Toetzer, 2003; Parker et al., 2008), and non-monetary influences in decision making (Evans and Kelley, 2004; Matthews et al., 2007).

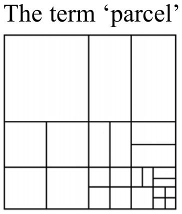
Land fragmentation is inevitable in amenity landscapes as new land owners acquire relatively small lots that have been segregated from larger agricultural and pastoral properties. Studies conducted in Australia confirm that land subdivision in rural areas is connected to in-migration (Bunker and Houston, 2003; Burnley and Murphy, 2004), therefore, it is important that an agent-based land use model developed for these landscapes encompasses land subdivision and associated ownership transfer processes.

Few studies model land subdivision either as an integrated module in a land use model, or as a stand alone application. Alexandridis and Pijanowski (2007) use a parcelization algorithm in an agent-based landscape model. In a separate study, Ko *et al*. (2006) develop a model called 'FLOSS' to simulate ownership fragmentation. Both these land subdivision automation attempts are made for raster-based landscape models at relatively coarse resolutions. Street generation that should accompany a realistic land subdivision is missing in both studies. Ashwini (2001) uses a semi-automated tool to generate realistic subdivision layouts using a vector parcel model. This tool is capable of generating large-scale subdivision layouts (both lot and street arrangement). However, its semi-automated nature limits its use in a simulation model. Venegas *et al*. (2008) develop a fully automated parcel subdivision module which is capable of generating both lot and street arrangements. However, the module uses recursive binary division on an initial parcel until lots of desired size are achieved and is computationally complex.

The objective of this study is thus to develop a fully automated parcel subdivision procedure that generates complete subdivision layouts showing both lot and street arrangement for a given parcel/parcels/existing street arrangement in a landscape using a vector data model while remaining relatively simple computationally.

2. PARCEL SUBDIVISION AUTOMATION

The term 'parcel' is used here to describe a land area that is managed as a single, relatively large unit and which is the target of the subdivision process. The term 'lot' defines a relatively small, single subdivided unit of land resulting from the subdivision of a much larger parcel.



This automation deals with rectangular land survey systems (Figure 1), where all the parcels are either rectangular or square in shape.

Figure 1. A Rectangular Land Survey System (Source: www.landsalesco.com).

Lot length and lot width are key parameters of the automation, and these can be readily determined using minimum lot sizes stated in local zoning regulations. The subdivision automation is capable of generating subdivision layouts for either all candidate parcels or for a selected parcel/parcels in a given landscape. In pursuing this objective, the automation strives to achieve the maximum number of lots for each target parcel while creating the least possible number of new streets. The procedure also ensures that all the lots in the subdivision layout have access to at least one street.

2.1 Logical Framework

It is assumed that each target parcel is served by at least one street prior to subdivision. A given parcel can be subdivided mainly in four distinct ways to generate different subdivision layouts in terms of lot and street arrangement (Figure 2). In Figure 2, P_w is the parcel width, P_l is the parcel length, L_w is the lot width, L_l is the lot length and s is the street width.

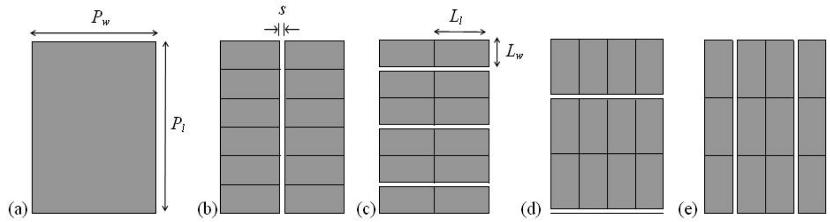


Figure 2. (a) Candidate parcel, (b) Subdivision layout: Lot length parallel to parcel width and streets parallel to parcel length, (c) Lot length parallel to parcel width and streets parallel to parcel width, (d) Lot length parallel to parcel length and streets parallel to parcel width, (e) Lot length parallel to parcel length and streets parallel to parcel length.

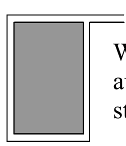
In subdivision layouts (b) and (d) of Figure 2, access to lots are granted along lot width, whereas in layouts (c) and (e) access is along lot length. A stack of lots is termed 'a block of lots'. The maximum number of lots potentially subdivided from a given parcel under given lot and street dimensions may vary among four subdivision layouts. For example, the layout shown in Figure 2(b) has two blocks of lots and six rows of lots.

For a given parcel, the subdivision automation procedure calculates the maximum possible number of lots and associated minimum number of streets for all four subdivision layouts in memory. The layout which generates the highest number of lots is chosen as the preferred subdivision procedure with which to progress. In the case of two or more subdivision layouts generating the same highest number of lots, the preferred subdivision layout is the one which generates the lowest number of streets. If it is still impossible to prioritize a subdivision layout using this second criterion, the layout shown in Figure 2(b) is selected as it is the most commonly used subdivision layout in land surveying. The selected layout is passed onto the next sections of the automation which then carry out the actual parcel subdivision to generate new lots and streets.

The process of calculating maximum number of lots and associated minimum number of streets while maintaining access to all lots under a given subdivision layout is not straight forward and is explained further in the next sections.

2.1.1 Existing streets around a parcel

Prior to subdivision, a parcel can be served by zero, one or two streets running adjacent to its length. Similarly, there can be zero, one or two streets adjacent to parcel's width. Therefore, a rectangular parcel can be served at most by four streets running along its four sides. The number of total existing streets for a given parcel can never be zero because this would violate the property law, 'ingress, egress, and regress'.



When a street loops around the entire parcel (Figure 3), the subdivision automation procedure treats this as two streets adjacent to parcel width and two streets adjacent to parcel length.

Figure 3. A single street looping around the entire parcel.

A street running adjacent to a side of the parcel is counted as an existing street only if that street/streets extends along the full length of that side. For example, side 'A' of parcel 'X' in Figure 4 is considered to have no adjacent street.

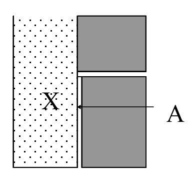


Figure 4. Incomplete existing adjacent streets.

2.1.2 Calculating new street requirement

This calculation is explained using the subdivision layout shown in Figure 2(b) as an example. Given the number of ‘blocks of lots’ and ‘rows of lots’ expected to be generated from a given parcel (explained in section 2.1.3) and the number of existing streets along four sides of the parcel, it is possible to calculate the minimum number of new streets required to provide access to all the generated lots.

If number of ‘blocks of lots’ (b) is an odd number, the quotient of integer division $b/2$ is m, and the number of existing streets adjacent to parcel length (e_l) is zero, the minimum number of new streets required parallel to parcel length (n_l) is given by;

$$n_l = m + 1 \tag{1}$$

If b is odd and e_l is either 1 or 2;

$$n_l = m \tag{2}$$

Figure 5 shows examples for each of the above situation using a case of three blocks. Note in the Figure 5 that the hatched symbol represents existing streets while white stripes between blocks of lots represent new streets.

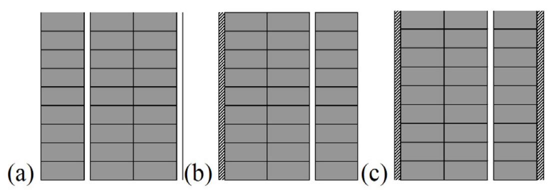
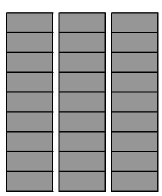


Figure 5. Subdivision layouts for odd number of ‘blocks of lots’ (a) zero existing streets along parcel length, (b) one existing street along parcel length, (c) two existing streets along parcel length.

To provide access to all lots in the layout shown in Figure 5(a), two new streets must be created parallel to parcel length. The same number of new streets can be maintained in a slightly different layout, while having the same number of lots (Figure 6).



However, the layout in Figure 5(a) is preferred over layout shown in Figure 6 because the former generates a new street along one side of the original parcel. This particular street can serve as an existing street for the adjacent parcel, thus decreasing the total number of new streets generated in the entire landscape.

Figure 6. An alternative subdivision layout for Figure 5(a).

When b is an even number and e_l is either zero or 1, n_l can be calculated using equation 2. If b is even and e_l is 2;

$$n_l = m - 1 \tag{3}$$

Figure 7 shows examples for these cases using four blocks of lots.

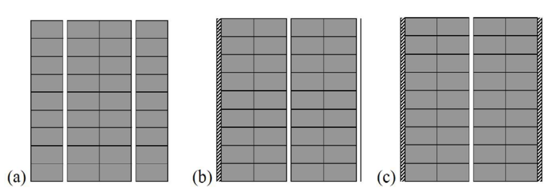
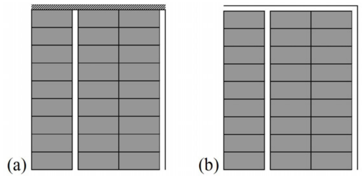


Figure 7. Subdivision layouts for even number of ‘blocks of lots’ (a) zero existing streets along parcel length, (b) one existing street along parcel length, (c) two existing streets along parcel length.

As new streets are created along parcel length (or along blocks), it is important that these are connected to the existing street network. If there is at least one existing street adjacent to parcel width [Figure 8(a)], new streets generated parallel to parcel length are connected



to the available street network. However, if that is not the case, a new street must also be created parallel to parcel width [Figure 8(b)].

Figure 8. (a) Subdivision layout with an existing connecting street, (b) Subdivision layout with a new connecting street.

There can be instances where a new street/s must be created to give access to lots along lot width for a given layout, but another layout would require either no or less number of new streets to provide access to a similar number of lots (Figure 9). In such situations, the latter subdivision layout (Figure 9b) is preferred over the former (Figure 9a).

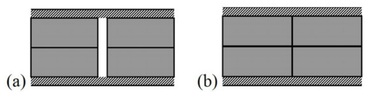


Figure 9. (a) Subdivision layout giving access along lot width, (b) Subdivision layout giving access along lot length.

2.1.3 Arriving at final number of blocks of lots, rows of lots and new streets

This process is also explained using the subdivision layout in Figure 2(b).

***Step 1*:** Given the parcel width (P_w) and lot length (L_l), the number of blocks of lots (b) can be calculated using equation 4.

$$P_w / L_l = b + R \tag{4}$$

where b is the quotient and R is *remainder*/L_l.

***Step 2*:** The remaining parcel width which can be used to accommodate new streets can be calculated by;

$$\text{Width left to accommodate new streets } (T_r) = R \times L_l \tag{5}$$

***Step 3*:** The next step is to calculate the number of new streets required (n_l) to accommodate b using the procedure explained in section 2.1.2. If street width is s, total width required to accommodate all new streets (T_s) can be calculated as;

$$T_s = n_l \times s \tag{6}$$

***Step 4*:** If $T_s \leq T_r$, the calculation stops at this point. Else, the calculation proceeds to step 5.
***Step 5*:** One block should be dropped to find width to accommodate new streets. New T_r is therefore given by;

$$T_r = (R \times L_l) + (b_d \times L_l) \tag{7}$$

where b_d is the number of dropped blocks.

Dropping one block automatically calls for the recalculation of the new street requirement. Therefore, a new number of streets (n_l) is calculated for the now reduced number of blocks. This means that steps 3 to 5 are repeated until the final number of blocks (b^*) and new streets (n_l^*) are found.

Once final number of streets (n_l^*) is known, it is possible to calculate the total width required to accommodate n_l^* using equation 6. Therefore, total width left along parcel width (W_r) to accommodate final number of blocks is given by;

$$W_r = P_w - (s \times n_l^*) \tag{8}$$

Final lot length (L_l^*) is therefore;

$$L_l^* = W_r / b^* \tag{9}$$

Hence, final lot length is either equal to or slightly higher than the user specified lot length.

Similarly, given the parcel length (P_l) and the lot width (L_w), the number of rows of lots (r) can be calculated as;

$$P_l / L_w = r + R \tag{10}$$

where r is the quotient and R is *remainder*/L_w.

As previously mentioned, there should be at least one street running adjacent to the parcel width. This street can act as a '*connecting street*' for those streets running parallel to and in between blocks of lots. If there is an already existing connecting street, the final number of rows of lots is the r given in equation 10. Otherwise one new connecting street is also created running parallel to parcel width (Figure 8b). If this is the case, $L_w \times R$ (from equation 10) should be greater than street width (s) to accommodate a new connecting street within the remaining parcel length. When this condition is not met, one row of lots should be dropped to find room to accommodate the new connecting street. In this case, dropping just one row of lots is enough (assuming L_w is always greater than s). When this happens, the final number of rows of lots becomes $r - 1$. This also means that final lot width (L_w^*) is slightly higher than the user specified lot width (L_w). L_w^* can be calculated as;

$$L_w^* = \frac{P_l - s}{r - 1} \tag{11}$$

2.1.4 Deciding location of streets in special situations

Assume that a parcel should be subdivided based on the layout in Figure 2(b), and that this parcel does not have adjacent streets to any of the longer sides. If the final number of blocks of lots is an odd number (e.g. 3), only one new street should be placed towards the most right or left of the original parcel. The rest of the new streets are placed somewhere in the middle of the original parcel. In such a situation, the total area of the first order neighbouring parcels is calculated separately for left and right sides of the target parcel. If the total area of neighbouring parcels adjacent to the right side of the target parcel is higher, then one new street is placed towards the most right side of the target parcel. Figure 10 shows an example for this scenario.

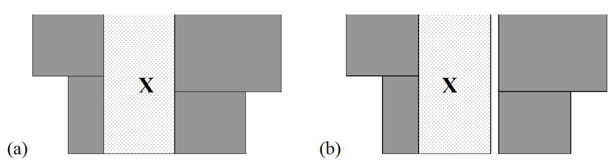


Figure 10. New street generation – a special case.

A similar approach is followed when deciding the location for a new connecting street.

2.2 Implementation

The land subdivision automation described above is implemented as a macro in ArcGIS software using ArcObjects and VBA programming. The user must specify the location of candidate parcels and initial street arrangement for those parcels via a polygon shapefile, whereby both parcels and streets are polygon features represented within a single shapefile. It is important that this shapefile is free from geometric errors. As a precaution, the user can run the shapefile through the 'repair geometry' tool found in ArcGIS. The attribute table of the shapefile should contain two additional attributes; 'Label' and 'Shape_Area'. 'Label' should only contain two attribute values; ‘parcel’ and ‘street’. ‘Shape_Area’ contains actual area of each polygon.

The macro evaluates the first parcel passed in for all four subdivision layouts, and selects the best layout. Then it generates lots and new streets according to the selected layout to match automatically calculated parameters (based on user specified constraints such as minimum lot width, lot length and street width). These are: final number of ‘blocks of lots’, new streets, ‘rows of lots’ and connecting streets. Subsequently, the original parcel is replaced with the newly generated lots and streets, and then the macro subdivides the next parcel if requested.

Subdivision of one parcel can affect the subdivision layout of neighbouring parcels, because the new streets generated during subdivision can serve as existing streets for neighbouring parcels. For this reason, the order in which parcels are taken in for subdivision affects the total number of lots and new streets generated in the entire landscape.

2.3 Preliminary Results

The subdivision automation can be used to generate subdivision layouts for a selected parcel or all parcels in the landscape based on three user inputs; 1) lot length, 2) lot width and 3) street width. Figure 11 shows three candidate parcels and their initial street arrangements, and actual subdivision layouts generated by the macro for two scenarios. For these examples, street width is set to 40m.

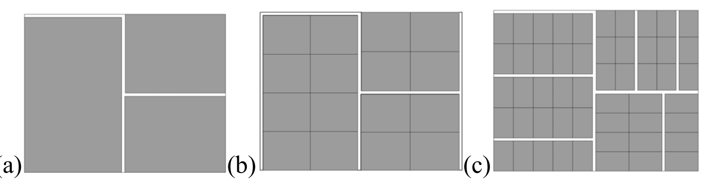
(a) (b) (c)


Figure 11. (a) Target parcels and initial street arrangement, (b) subdivision layouts for 650m lot width * 800m lot length, (c) subdivision layouts for 300m lot width * 450m lot length.

This subdivision automation can also be used to generate subdivision layouts to match different zoning regulations. Moreover, the automation takes less than ten seconds to subdivide an area of 6km*8km that contains nine large parcels into 92 lots of 550m*750m, and less than twenty five seconds to subdivide the same area into 293 lots of 300m*450m.

3. CONCLUSIONS AND RECOMMENDATIONS

The land subdivision automation explained in this paper attempts to generate subdivision layouts for a given parcel in a way that maximizes the number of lots while minimizing the number of new streets generated under the constraints of minimum lot width, lot length and street width. It also tries to minimize the total number of new streets created in the entire landscape by promoting the use of new streets created for a given parcel as existing streets for neighbouring parcels. However, the actual total number of lots and new streets generated for the entire landscape also depends on the order in which parcels are subdivided. Therefore, it is possible to run the automation for several such orders, and determine the order that generates new streets equal to or under a desired number, while retaining a higher number of lots at the landscape level. Alternatively, a genetic algorithm-based optimization solution could be implemented where different lot lengths and widths (within the constraint of minimum lot size) and various random orders of subdivision are explored to find the best parameters and subdivision order for a given landscape/zone. We hope to examine this further as we continue to refine and develop the tool.

Using this automation with an agent-based land use model currently requires knowing the order of subdivision used by the land use model is known in advance. This works well when the subdivision order is random, for example. If the order of parcel subdivision is decided dynamically by the land use model as it progresses over time, some form of communication should be established between the agent-based platform and ArcGIS software platforms, whereby the land use model requests subdivision layout for a particular parcel and subdivision automation responds with the layout. On the other hand, it is also possible to re-code this subdivision automation procedure within the software platform used by the land use model.

Many other application areas may benefit from the subdivision automation presented here. Environmental planners and policy makers could use the automation to analyse habitat fragmentation due to land development, gaining an estimate and a means of visualising how habitats are fragmented and lost due to differing subdivision schemes. This would assist governing bodies to set appropriate zoning regulations to minimize the negative effects of land subdivision on biodiversity. An upcoming paper will deal with this and several other applications of the subdivision automation in detail.

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