Drawing Game Trees with Ti*k*Z

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Abstract

Game trees, also known as extensive form games, are commonly used to represent situations of strategic interactions. This document provides examples on how to produce nice looking game trees in LaTeX with the Ti*k*Z package.[1]

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[*]Comments and suggestions are welcome. Please send them to haiyunc@sfu.ca.

[1]An alternative way to draw game trees in LaTeX is to use the PSTricks package, and Martin Osborne has created a style for this purpose (see its documentation for detail).

1 Preliminaries

The TikZ package, which comes with standard LATEX distributions. In the preamble, load the package with:

    `\usepackage{tikz}`

It will be helpful also to use the `calc` library in TikZ for calculations of coordinates:

    `\usetikzlibrary{calc}`

The coloring of the figures is done through the `xcolor` package:

    `\usepackage[dvipsnames]{xcolor}`

2 Drawing Game Trees with TikZ

2.1 The `tikzpicture` Environment

The TikZ commands take effect in the TikZ environment. While there are numerous ways to introduce the TikZ environment,[2] in this article we focus mainly on the `tikzpicture` environment, which can be introduced, as other environments in LATEX, with the following syntax:

    `\begin{tikzpicture}[`*options*`]`
      `\`*command_name* `[`*options*`] ... ; % This is a 'path' in TikZ.`
    `\end{tikzpicture}`

---

[2]See the [TikZ & PGF Manual](#) for detail.

A typical path in Ti*k*Z generally starts with *command_name*, and ends with a semicolon (;). It is permissible to have multiple commands (or operations, as they are called in the manual) within a given path. Note, however, for the nested commands (e.g. the second to fourth node{} command in Figure 1), the "\" sign must be omitted.

2.2 Trees in Ti*k*Z

In Ti*k*Z, tree diagrams starts with a "root", usually produced by the command \node{}, and each successor node that directly connects to the root is a "child" of the root node.[3] Each child is a node itself, and thus can have its own "children". Figure 1 illustrates this general structure.

<div style="display: flex;">

root

/ \

child 1   child 2

/ \

grandchild 1   grandchild 2

```
\begin{tikzpicture}
  \node(0){root}
      child{node{child 1}}
      child{node{child 2}
        child{node{grandchild 1}}
        child{node{grandchild 2}}
      };
\end{tikzpicture}
```
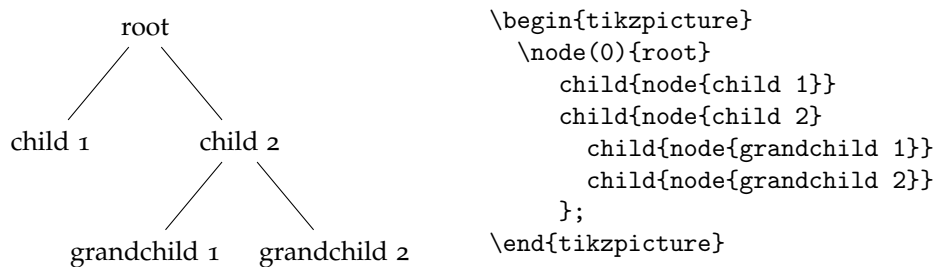
</div>

Figure 1: General Structure of Trees in Ti*k*Z

The most important Ti*k*Z command used to draw game trees is

...node(*coordinate label*) [*drawing/style options*] at(*coordinate*) {*node texts*}...;

The *coordinate labels* and *drawing/style options* are optional; at(*coordinate*) is also optional and allows one to put the node at a specific position; *node texts* can be omitted, but the braces {} are required. The *coordinate label* makes it easy to refer to the position of the node in later drawing, e.g. to add payoff vectors or information sets. The *coordinate label* can also be used to refer to the children of the node. For example, the root node in Figure 1 is labeled "0", and so the coordinate of child 1 can be referred to as (0-1), and that of grandchild 1 can be referred to as (0-2-1).

The command child{} is used to specify a successor of a (parent) node. In Figure 1, the first two child commands specify the successors of the root node, and the last two specify the successors of child 2 (hence the grandchildren of the root node). Inside the child{} command is usually another node{}, which determines the style of the child node, and edge from parent, which governs the style of the branch that connects the

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[3]To draw other general trees with Ti*k*Z, see Section 18: Making Trees Grow of the manual.

child to its parent. Note that if the style of a particular branch needs to be modified, such as adding texts to the branch or changing its color, `edge from parent` must be put <u>after</u> `node{}` and all of its children.

2.3 Formatting Nodes

Various textbooks use circles, such as ○ and ●, to indicate different nodes on a game tree.[4] In Ti*k*Z this can be easily achieved by specifying a style for the `node` command. The solid and hollow circle styles can be set using either `\tikzstyle` or `\tikzset`:

> `\tikzstyle{`*style name*`}=[`*style options*`]`

or, if we would like to set multiple styles in one go,

> `\tikzset{`
>   *style name 1*`/.style={`*style options*`}`
>   *style name 2*`/.style={`*style options*`}`
> `}`

Both of these commands can be used outside the `tikzpicture` environment, and so they need not be suffixed with a semicolon (`;`). Also, if a Ti*k*Z style is going to be repeatedly used throughout the same document, it can be set using `\tikzset` in the preamble. The following example shows how this is implemented.


```
\begin{tikzpicture}
  \tikzstyle{hollow node}=[circle,draw,inner sep=1.5]
  \tikzstyle{solid node}=[circle,draw,inner sep=1.5,fill=black]
  \tikzset{
    red node/.style={circle,draw=red,fill=red,inner sep=1.2},
    blue node/.style={rectangle,draw=blue,inner sep=2.5}
  }
  \node[hollow node]{}
    child{node[solid node]{}}
    child{node[red node]{}}
    child{node[blue node]{}}
  ;
\end{tikzpicture}
```

---

[4]For example, Mas-Colell, Whinston, and Green (1995, henceforth MWG) and Osborne and Rubinstein (1994) use the hollow circle to indicate the initial node, while non-initial nodes are denoted by solid circles.

In the code, `circle` (and `rectangle`) specifies the shape of a node; `draw`=*color* asks Ti*k*Z to draw the boundary of the node with *color*;[5] `inner sep`=*parameter* determines—for the purpose of this article—the size of the node;[6] and `fill`=*color* fills the interior of a node with *color*.

2.4   Information Sets

Information sets in game trees are usually represented as either dashed lines joining the nodes in an information set (●- - - -●), or elongated circles encompassing those nodes (●̄‾‾‾●̄). To implement these drawings in Ti*k*Z, we can use the `\draw` command:

> `\draw`[*drawing options*] (*coordinate_1*) *path operation* (*coordinate_2*)
>   *path operation* (*coordinate_3*) ... ;

The *coordinate*s can be referred to using *coordinate labels* of the `node{}` command; *path operation* allows us to draw, for example, straight lines and curves from one coordinate to the next (with the operation `to`), or rectangles with two diagonal angles at *coordinate_1* and *coordinate_2* (with the `rectangle` operation). In the following examples, let the initial node be labeled "0", so that the coordinate of its ith child (from the left) can be referred to as (`0-i`). Here is a simple dash-line information set:
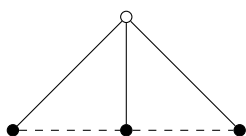
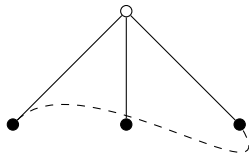`\draw[dashed](0-1)to(0-2)to(0-3);`

A curved, dash-line information set:
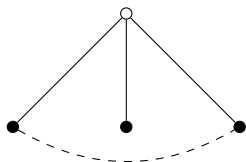
`\draw[dashed,bend right](0-1)to(0-3);`

To have more flexible curvature, use the [`out`=*angle*,`in`=*angle*] option to specify the degrees at which the line starts and ends:

---

[5]The default color is black, when *color* is not specified.

[6]In fact, `inner sep` specifies the space between the texts within a node and its boundary. In the examples presented in this article, most nodes within a tree will not have textual content. Therefore `inner sep` is primarily used to determine the node sizes.

```
\draw[dashed,out=45,in=300](0-1)to(0-3);
```

Color and line style options can easily be added as well:
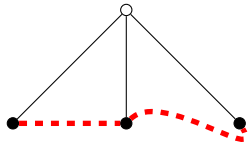
```
\draw[dashed,draw=red,line width=2pt]
  (0-1)to(0-2)to[out=45,in=300](0-3);
```

Drawing a "circled" information set is more involved. The idea is to draw a rectangle (with rounded corners) that encloses the nodes in the same information set. In the \draw command, we use rectangle as the *path operation*. Suppose there are two nodes, left and right, in an information set, with coordinate labels (0-1) and (0-2), respectively. We want the northwest corner of the rectangle placed above and to the left of the left node, and the southeast corner placed below and to the right of the right node.[7] The positions of the northwest and southeast corners, to be used as *coordinate_1* and *coordinate_2* in the \draw syntax, are relative to the positions of the two nodes. Hence, they can be calculated as relative coordinates to (0-1) and (0-2).

The calc library provides a method for calculating relative coordinates. Suppose the position (a_1, a_2) of a coordinate labeled (A) is known. Then the coordinate $(a_1 + x, a_2 + y)$ is given by the syntax: ($(A)+(x,y)$), where x and y are any real numbers.

Therefore, a circled information set can be drawn as follows:
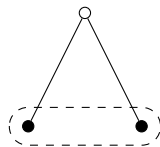
```
\draw[dashed,rounded corners=7]
  ($(0-1)+(-.25,.25)$)rectangle($(0-2)+(.25,-.25)$);
```

Figure 2: Game Tree with a Circled Information Set

Here, the rounded corners=*parameter* determines how "rounded" the corner is.[8] Other drawing options can be added as usual.

Sometimes we may want to circle a single node, e.g. node 0 in Figure 2, to indicate that it is a singleton (or trivial) information set. This is more easily done using circle as

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[7] Alternatively, we could have the southwest corner of the rectangle positioned below and to the left of the left node, and the northeast corner above and to the right of the right node.

[8] Depending on the size of the rectangle, the parameter value may have to be manually adjusted.

the *path operation* for the \draw command. When drawing a circle, *coordinate_1* indicates the center of the circle and *coordinate_2* specifies its radius:
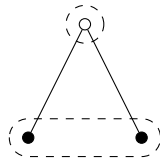
```
\draw[dashed](0)circle(.25cm);
\draw[dashed,rounded corners=7]
  ($(0-1)+(-.25,.25)$)rectangle($(0-2)+(.25,-.25)$);
```

2.5 Adding Texts

In a game tree, texts are needed to indicate, for instance, the mover at a particular information set, the payoffs, the action represented by a branch, etc. These can be added via the node{} command, whose syntax was introduced on , or sometimes even simpler, through the label option for the node{} command:

   ...node[label=*position parameter*:{*label texts*}]{}...;

The *position parameter* can take either string values such as above, left, right, below, above right, above left, below right, below left, or numeric values indicating the angle (relative to the center of the node) at which the label should be placed. Take Figure 2 as an example. Suppose we want to specify movers at the two information sets, with Nature moving at the top one and Bob moving at the bottom one.
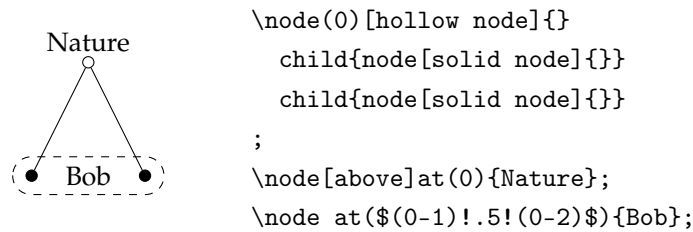
   To position the text "Nature" above the initial node, it is much easier to use the label option:
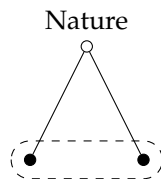
```
\node(0)[hollow node,label=above:{Nature}]{}
  child{node[solid node]{}}
  child{node[solid node]{}}
;
```

The text "Bob" should be placed in the circle, centered between the two solid nodes. But since there is no node defined at that position, we cannot use the label option again. Instead, we will have to use the node{} command. Adding texts with the node{} command is usually done after the tree is drawn and all its nodes properly labeled. To put texts in a particular position, we can use the at(*coordinate*) option. While we don't know the exact coordinate where "Bob" needs to be placed, we know that it is the midpoint between (0-1) and (0-2). Here the calc library proves handy again. If we want to refer to the coordinate half of the way from (0-1) to (0-2), we simply use

($(0-1)!.5!(0-2)$).[9] As an aside, we can also see how "Nature" can be added using node{}:

<table>
<tr><td>Nature
○
Bob</td><td>

```
\node(0)[hollow node]{}
  child{node[solid node]{}}
  child{node[solid node]{}}
;
\node[above]at(0){Nature};
\node at($(0-1)!.5!(0-2)$){Bob};
```
</td></tr>
</table>

Notice that the option [above] is given to indicate that "Nature" is above point (0). Other position options are similar to those used in the label option. Two very useful position options are worth mentioning: xshift=*parameter* and yshift=*parameter*. These options allows one to shift the node position horizontally and vertically by any unit, and so are particularly useful when fine-tuning the figure.

Other texts such as payoff vectors can be added similarly. The next subsection goes over how to format and to add texts to the branches.

2.6 Formatting Branches

The style/formatting of the branches is controlled through edge from parent[*options*], which should be put as a second operation of child{}—the first operation should be node{}.[10] The basic *options* are more or less the same as those for \draw. Texts are added using a second node{} command, after edge from parent.[11] The next example illustrates how branches can be decorated:

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[9]The !.5! in the example could be replaced with other numbers as well. For instance, !.75! would give the coordinate three quarters on the way from (0-1) to (0-2). To find the midpoint between two coordinates, we could alternatively use ($.5*(0-1)+.5*(0-2)$), a syntax consistent with the one used in Figure 2. Still another method is to use the [midway] option of node{} in conjunction with \draw. To put "Bob" in the right place, we could instead have used \draw[draw=none](0-1)to(0-2) node[midway]{Bob};. The [draw=none] option basically tells Ti*k*Z to draw an invisible line, and the [midway] option puts a node in the middle of this invisible path.

[10]Note that it is not necessary to separate the two operations with anything.

[11]Unfortunately the label option does not work with edge from parent. So branch texts must be added using node{}.
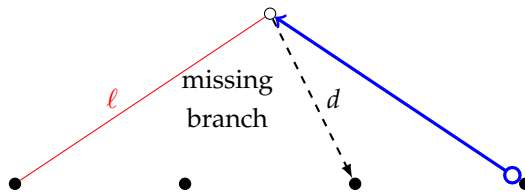
```
\node(0)[hollow node]{}
  child{node[solid node]{} edge from parent[red] node[left,xshift=-5]{$\ell$}}
  child{node[solid node]{} edge from parent[draw=none] node[align=center]{missing\\branch}}
  child{node[solid node]{} edge from parent[->,>=latex,dashed,thick] node[xshift=8]{$d$}}
  child{node[solid node]{} edge from parent[<-o,blue,very thick]}
;
```

Often the style of the branches are uniform throughout the whole tree. Therefore, the branch styles can be set at the beginning of the tikzpicture environment with

\begin{tikzpicture}[edge from parent/.style={draw, *other style options*}]

Note that unless you don't want the branches to be drawn, you should always put draw as one of the options to edge from parent.[12]

2.7 Sibling and Level Distances

Consider the example given in Section 2.5. Suppose, instead of Bob being the mover in the bottom information set, it was Alexander. Intuitively, you would think that we could simply replace "Bob" with "Alexander":
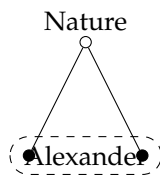

```
\node(0)[hollow node]{}
  child{node[solid node]{}}
  child{node[solid node]{}}
;
\node[above]at(0){Nature};
\node at($(0-1)!.5!(0-2)$){Alexander};
```

But the problem is that "Alexander" is too long a word to fit between the two solid nodes. The solution: widen the distance between the two nodes! There are several ways to do this using the [sibling distance=*parameter*] option.[13]

---

[12]In case you do want certain branches not to be drawn, you can simply pass the option [missing] to the child command, instead of fiddling with edge from parent, which has more typing.

[13]The default value for sibling distance is 15 mm.

Method 1. Give the [sibling distance=*parameter*] option to each `child{}`:

Nature

Alexander

```
\node(0)[hollow node]{}
  child[sibling distance=25mm]{node[solid node]{}}
  child[sibling distance=25mm]{node[solid node]{}}
;
\node[above]at(0){Nature};
\node at($(0-1)!.5!(0-2)$){Alexander};
```

Method 2. Use the option before the first `child{}` command:

Nature

Alexander

```
\node(0)[hollow node]{}
  [sibling distance=25mm]
  child{node[solid node]{}}
  child{node[solid node]{}}
;
\node[above]at(0){Nature};
\node at($(0-1)!.5!(0-2)$){Alexander};
```

Method 3. Specify a level style:

Nature

Alexander

```
\tikzstyle{level 1}=[sibling distance=25mm]
\node(0)[hollow node]{}
  child{node[solid node]{}}
  child{node[solid node]{}}
;
\node[above]at(0){Nature};
\node at($(0-1)!.5!(0-2)$){Alexander};
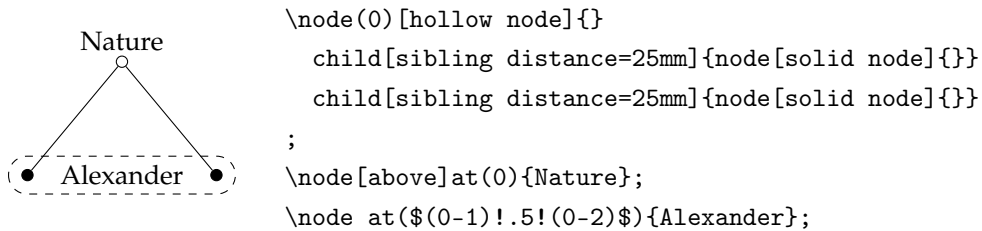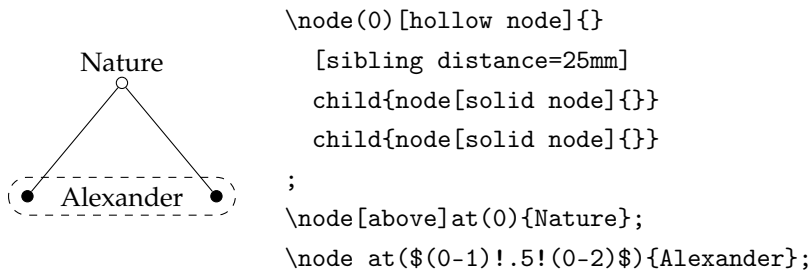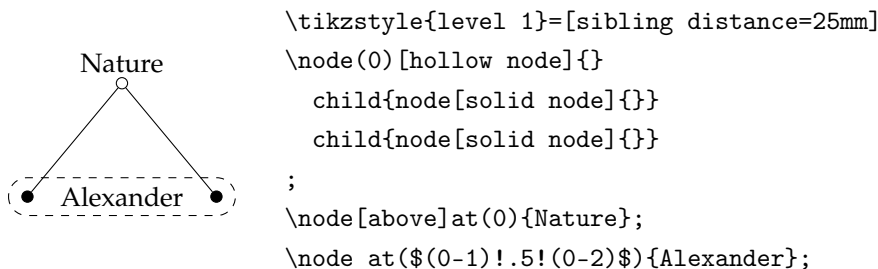```

A level style applies to all nodes in a particular level. Using the language in Figure 1, all children of the root node are level 1 nodes, and all grandchildren are level 2 nodes. Using the third method is, personally speaking, preferred, as it maintains a uniformity of style across all nodes in the same level. Moreover, one can always override the level style by giving options to any particular `child{}`, as exemplified in Method 1.
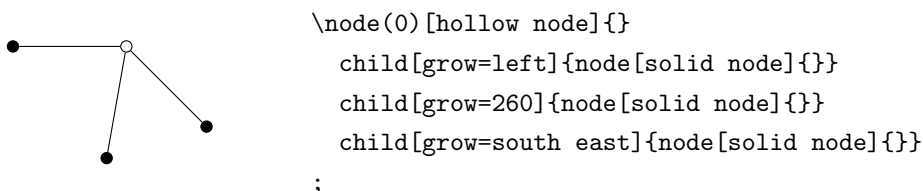
In addition to `sibling distance`, one can also specify `level distance` in a similar manner.[14]

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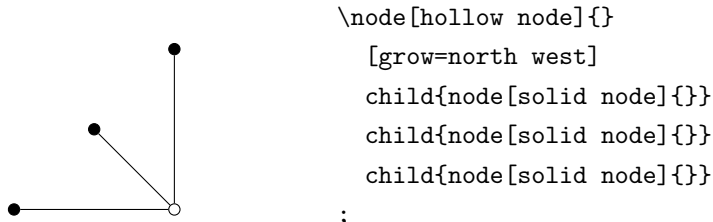[14]The default for `level distance` is also 15 mm.

## 2.8 Miscellaneous Issues

### 2.8.1 Directions of "Growth"

One may, on occasion, find the need to make a game tree, or certain branches of the tree, grow in other directions than downwards, such as in the Bayesian games or in a centipede game. To make a particular branch grow in a certain direction, give the option [grow=*direction parameter*] to the `child{}` to which that branch leads. The *direction parameter* can take either numeric values from −360 to 360, indicating the angle towards which the tree grows, or text strings such as up, down, left, right, north, south west, north east, etc. For example,

```
\node(0)[hollow node]{}
  child[grow=left]{node[solid node]{}}
  child[grow=260]{node[solid node]{}}
  child[grow=south east]{node[solid node]{}}
;
```

If, on the other hand, we want to whole tree to grow in a certain direction, then the [grow=*direction parameter*] option can be put before the first `child{}`, as in Method 2:

```
\node[hollow node]{}
  [grow=north west]
  child{node[solid node]{}}
  child{node[solid node]{}}
  child{node[solid node]{}}
;
```
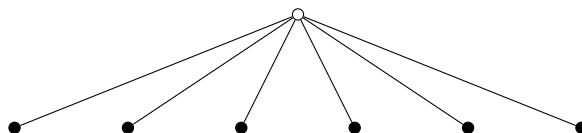
2.8.2 Automating Text Input

If the texts in a game tree, for example the payoffs, exhibit some regular pattern, we can simplify the inputting process using loops. Ti*k*Z offers the `\foreach` loop:

    `\foreach` *index_name* in {*set of index values*} *command_name* ... ;

Suppose we want to enter the payoff vectors below the six solid nodes in the following tree:

We know that if we call the hollow node (0), which we have been so far, then the solid nodes can be referred to as (0-i) where i is the ith child of (0) from the left. Suppose the payoff vectors are of the form (a_i, b_i) for the ith node. Then, instead of typing the `node{}` command or the `[label]` option six times, we can use

```
\foreach \i in {1,...,6} \node[below]at (0-\i) {$(a_\i,b_\i)$};
```
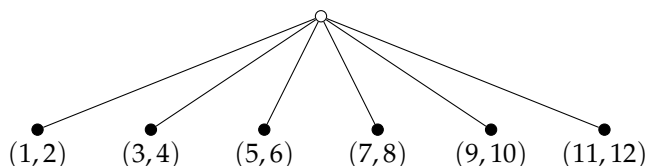
to produce
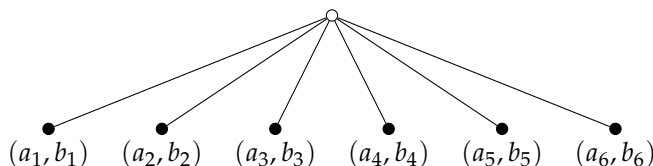
TikZ is very smart in figuring out the patterns in the {*set of index values*}, so we usually don't need to spell out each individual index value. For instance, if we want TikZ to perform an operation for all even numbers between 0 and 20, we need simply say `\foreach \x in {0,2,...,20} ...;`. This of course works with decimals as well.

Suppose the payoff vectors are $(1,2), (3,4), \ldots, (11,12)$ for the first to the sixth solid nodes. We could, as before, ask TikZ to enter $(2i-1, 2i)$ after each solid node i. TikZ is equipped with a mathematical engine that enables this kind of calculations.[15] The two commands we will be using in this case are `\pgfmathsetmacro` and `\pgfmathprintnumber`:

```
\pgfmathsetmacro\macro_name{math expression}
\pgfmathprintnumber{\macro_name}
```

The first command evaluates *math expression* and stores the result in *macro_name*, and the second command prints the result:


```
\foreach \i in {1,...,6}
  \pgfmathsetmacro{\payoffa}{2*\i-1}
  \pgfmathsetmacro{\payoffb}{2*\i}
  \node[below]at (0-\i)
    {$(\pgfmathprintnumber{\payoffa},\pgfmathprintnumber{\payoffb})$};
```

---

[15]In fact, it is PGF, the back end program for TikZ, that makes this evaluation of mathematical expressions possible. The relationship between TikZ and PGF is similar to the one between LaTeX and TeX.

Alternatively, we can use the counter function in LaTeX to accomplish the same goal:
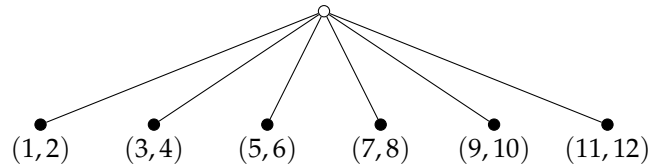

```
\newcounter{payoff}
\foreach \i in {1,...,6}
  \node[below]at (0-\i){
    $(\stepcounter{payoff}\arabic{payoff},\stepcounter{payoff}\arabic{payoff})$
  };
```

The first line of the code initiates a new counter called payoff.[16] In the fourth line, \stepcounter{payoff} increases the counter payoff by one, and \arabic{payoff} prints the counter value in Arabic numerals. Instead of numbers, one could also use \alph{} or \Alph{} to print lower- and upper-case latin alphabets:
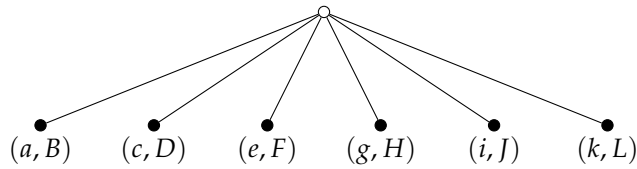

```
\newcounter{alphpay}
\foreach \i in {1,...,6}
  \node[below]at (0-\i){
    $(\stepcounter{alphpay}\alph{alphpay},\stepcounter{alphpay}\Alph{alphpay})$
  };
```

---

[16]The initial value of all new counters is automatically set to zero. To change this initial value to some other value, use \setcounter{*counter_name*}{*new_value*}.

3 Examples

3.1 A 2×2 Tree with Information Set
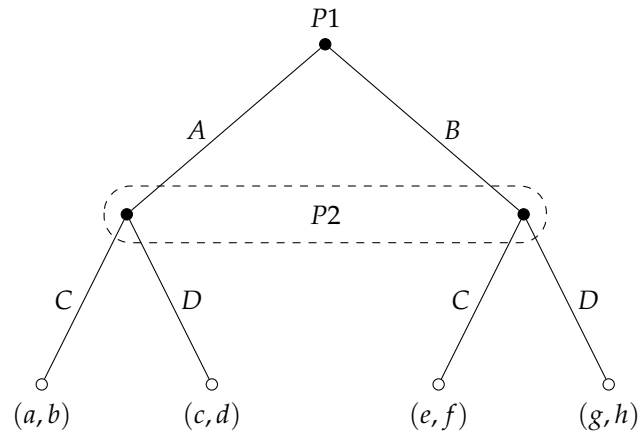
Figure 3: A 2 × 2 Tree with Information Set

Figure 3 is produced by the following codes:

```
% Node styles
  \tikzset{
    % Two node styles for game trees: solid and hollow
    solid node/.style={circle,draw,inner sep=1.5,fill=black},
    hollow node/.style={circle,draw,inner sep=1.5}
  }


\begin{tikzpicture}[scale=1.5,font=\footnotesize]
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=35mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=15mm]

  % The Tree
  \node(0)[solid node,label=above:{$P1$}]{}
    child{node(1)[solid node]{}
      child{node[hollow node,label=below:{$(a,b)$}]{} edge from parent node[left]{$C$}}
      child{node[hollow node,label=below:{$(c,d)$}]{} edge from parent node[right]{$D$}}
      edge from parent node[left,xshift=-3]{$A$}
    }
    child{node(2)[solid node]{}
      child{node[hollow node,label=below:{$(e,f)$}]{} edge from parent node[left]{$C$}}
      child{node[hollow node,label=below:{$(g,h)$}]{} edge from parent node[right]{$D$}}
      edge from parent node[right,xshift=3]{$B$}
    };
```

```
  % information set
  \draw[dashed,rounded corners=10]($(1) + (-.2,.25)$)rectangle($(2) +(.2,-.25)$);
  % specify mover at 2nd information set
  \node at ($(1)!.5!(2)$) {$P2$};
\end{tikzpicture}
```

This example exhibits several features:

1. It shows how node styles can be set outside of a `tikzpicture` environment.

2. A Ti*k*Z picture can be scaled by giving the option `scale=`*factor* to the `tikzpicture` environment.

3. Fonts within a Ti*k*Z picture can be changed using the `font=`{*attribute 1*, *attribute 2*, ...} option. When there is only one attribute, the braces {} are not required.

3.2 Asymmetric Tree
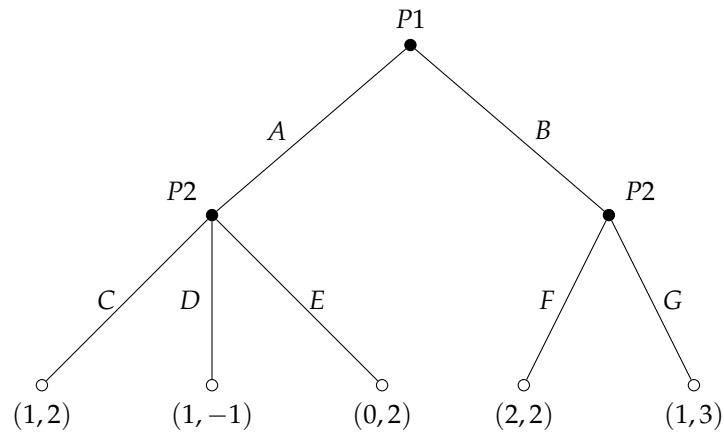
Figure 4: Asymmetric Tree

Codes that produce Figure 4:

```
\begin{tikzpicture}[scale=1.5,font=\footnotesize]
  \tikzstyle{solid node}=[circle,draw,inner sep=1.5,fill=black]
  \tikzstyle{hollow node}=[circle,draw,inner sep=1.5]
  \tikzstyle{level 1}=[level distance=15mm,sibling distance=3.5cm]
  \tikzstyle{level 2}=[level distance=15mm,sibling distance=1.5cm]
  \tikzstyle{level 3}=[level distance=15mm,sibling distance=1cm]

  \node(0)[solid node,label=above:{$P1$}]{}
    child{node[solid node,label=above left:{$P2$}]{}
      child{node[hollow node,label=below:{$(1,2)$}]{} edge from parent node[left]{$C$}}
      child{node[hollow node,label=below:{$(1,-1)$}]{} edge from parent node[left]{$D$}}
      child{node[hollow node,label=below:{$(0,2)$}]{} edge from parent node[right]{$E$}}
      edge from parent node[left,xshift=-5]{$A$}
    }
    child{node[solid node,label=above right:{$P2$}]{}
      child{node[hollow node,label=below:{$(2,2)$}]{} edge from parent node[left]{$F$}}
      child{node[hollow node,label=below:{$(1,3)$}]{} edge from parent node[right]{$G$}}
      edge from parent node[right,xshift=5]{$B$}
    };
\end{tikzpicture}
```

3.3 Sequential-Move Game

Figure 5: Asymmetric, Sequential-Move Game Tree with Information Set

Codes that produce Figure 5:

```
% macro for inputing payoff vectors
  \newcommand{\payoff}[4][below]{\node[#1]at(#2){$(#3,#4)$};}
%
\begin{tikzpicture}[scale=1,font=\footnotesize]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=20mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=23mm]
    \tikzstyle{level 3}=[level distance=15mm,sibling distance=11mm]
  % The Tree
  \node(0)[solid node]{}
    child{node(1)[solid node]{}
      child{node[solid node]{}
        child{node[hollow node]{}edge from parent node[left]{$F$}}
        child{node[hollow node]{}edge from parent node[right]{$G$}}
        edge from parent node[left]{$D$}
      }
      child{node[solid node]{}
        child{node[hollow node]{}edge from parent node[left]{$F$}}
        child{node[hollow node]{}edge from parent node[right]{$G$}}
        edge from parent node[right]{$E$}
      }
      edge from parent node[above left]{$A$}
    }
```

```
    child[missing]
    child[level distance=30mm,sibling distance=25mm]{node[solid node]{}
      [every child/.style={sibling distance=11mm}]
      child{node[hollow node]{}edge from parent node[left]{$H$}}
      child{node[hollow node]{}edge from parent node[left]{$I$}}
      child{node[hollow node]{}edge from parent node[right]{$J$}}
      edge from parent node[above right]{$B$}
    }
    child[grow=right,level distance=30mm]{node[hollow node]{}
      edge from parent node[above]{$C$}
    };
  % information set
  \draw[dashed,rounded corners=7]($(1-1)+(-.2,.25)$)rectangle($(1-2)+(.2,-.25)$);
  % specify movers
  \node[above]at(0){$P1$};
  \node at ($.5*(1-1)+.5*(1-2)$) {$P1$};
  \node[above left]at(1){$P2$};
  \node[above right]at(0-3){$P2$};
  % payoffs
  \payoff{1-1-1}ab
  \payoff{1-1-2}cd
  \payoff{1-2-1}ef
  \payoff{1-2-2}gh
  \payoff{0-3-1}ij
  \payoff{0-3-2}k{\ell}
  \payoff{0-3-3}mn
  \payoff[right]{0-4}pq
\end{tikzpicture}
```

All texts in this example are entered using the \node command after the tree is drawn. Part of the reason for doing this is to showcase the feature that one can define LaTeX macros that cuts down on the typing.[17] Since payoffs in a game tree usually involves mathematical texts, the macro \payoff in this example saves us the trouble of having to type, for every payoff vector, the $ signs, the parentheses (), and the comma separating the players' payoffs. While this may not seem like a huge reduction in typing, but as Figure 6 shows, macros can be extremely helpful when the texts to be entered have a certain pattern.

---

[17]See Wikibooks' introduction on how to define and use LaTeX macros.
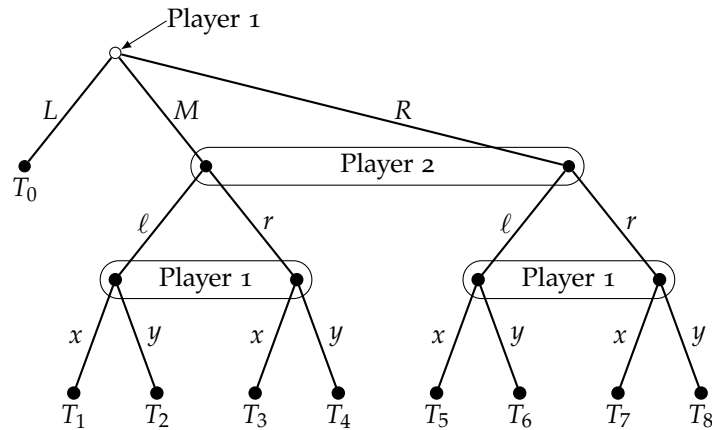
3.4 Market Entry Game

Figure 6: Replica of MWG Fig 7.Ex.1

Codes that produce Figure 6:

```
% macro for inputting terminal nodes
  \newcommand\term[2]{\node[below]at(#1){$#2$};}
%
\begin{tikzpicture}[font=\footnotesize,edge from parent/.style={draw,thick}]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=12mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=24mm]
    \tikzstyle{level 3}=[level distance=15mm,sibling distance=11mm]
  % The Tree
  \node(0)[hollow node]{}
    child{node[solid node]{}edge from parent node[left]{$L$}}
    child{node[solid node]at +(\tikzsiblingdistance,0){}
      child{node[solid node]{}
        child{node[solid node]{}edge from parent node[left]{$x$}}
        child{node[solid node]{}edge from parent node[right]{$y$}}
        edge from parent node[left]{$\ell$}
      }
      child{node[solid node]{}
        child{node[solid node]{}edge from parent node[left]{$x$}}
        child{node[solid node]{}edge from parent node[right]{$y$}}
        edge from parent node[right]{$r$}
      }
      edge from parent node[right]{$M$}
```

```
      }
      child[sibling distance=5*\tikzsiblingdistance]{node[solid node]{}
        child{node[solid node]{}
          child{node[solid node]{}edge from parent node[left]{$x$}}
          child{node[solid node]{}edge from parent node[right]{$y$}}
          edge from parent node[left]{$\ell$}
        }
        child{node[solid node]{}
          child{node[solid node]{}edge from parent node[left]{$x$}}
          child{node[solid node]{}edge from parent node[right]{$y$}}
          edge from parent node[right]{$r$}
        }
        edge from parent node[right,xshift=15]{$R$}
      };
    % information sets
    \draw[rounded corners=7]($(0-2)+(-.2,.25)$)rectangle($(0-3)+(.2,-.25)$);
    \draw[rounded corners=7]($(0-2-1)+(-.2,.25)$)rectangle($(0-2-2)+(.2,-.25)$);
    \draw[rounded corners=7]($(0-3-1)+(-.2,.25)$)rectangle($(0-3-2)+(.2,-.25)$);
    % specifying movers
    \draw[draw,<-,>=latex](0)--(32:8mm)node[right,inner sep=0]{Player 1};
    \node at ($.5*(0-2)+.5*(0-3)$) {Player 2};
    \node at ($.5*(0-2-1)+.5*(0-2-2)$) {Player 1};
    \node at ($.5*(0-3-1)+.5*(0-3-2)$) {Player 1};
    % specifying terminal nodes
    \newcounter{tnode}
    \setcounter{tnode}{0}
    \term{0-1}{T_\arabic{tnode}}
    \foreach \x in {2,3}
      \foreach \y in {1,2}
        \foreach \z in {1,2}
          \stepcounter{tnode}
          \term{0-\x-\y-\z}{T_\arabic{tnode}};
\end{tikzpicture}
```
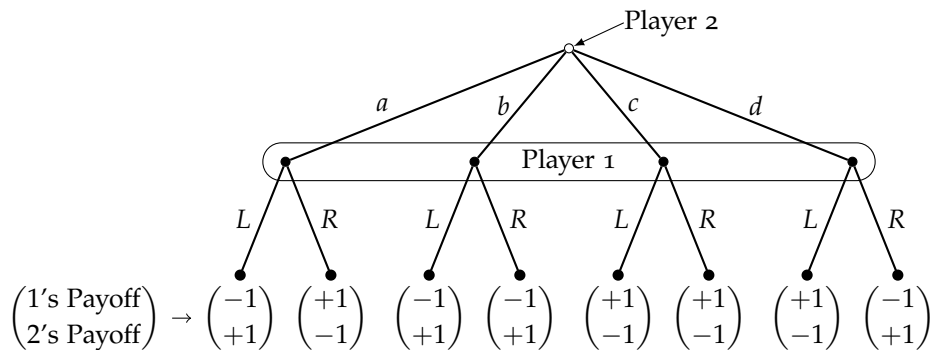
3.5 Large Information Set

Figure 7: Replica of MWG Fig 7.D.2

Codes that produce Figure 7:

```
\begin{tikzpicture}[font=\footnotesize,edge from parent/.style={draw,thick}]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=25mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=12mm]
  % The Tree
  \node(0)[hollow node]{}
    child{node[solid node]{}
      child{node[solid node]{}edge from parent node[left]{$L$}}
      child{node[solid node]{}edge from parent node[right]{$R$}}
      edge from parent node[left,xshift=-10]{$a$}
    }
    child{node[solid node]{}
      child{node[solid node]{}edge from parent node[left]{$L$}}
      child{node[solid node]{}edge from parent node[right]{$R$}}
      edge from parent node[left,xshift=0]{$b$}
    }
    child{node[solid node]{}
      child{node[solid node]{}edge from parent node[left]{$L$}}
      child{node[solid node]{}edge from parent node[right]{$R$}}
      edge from parent node[right,xshift=0]{$c$}
    }
    child{node[solid node]{}
      child{node[solid node]{}edge from parent node[left]{$L$}}
      child{node[solid node]{}edge from parent node[right]{$R$}}
      edge from parent node[right,xshift=10]{$d$}
```

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```
  };
% information set
\draw[rounded corners=7]($(0-1)+(-.3,.25)$)rectangle($(0-4)+(.3,-.25)$);
% specifying movers
\draw[<-,>=latex](0)--(25:8mm)node[inner sep=0,right]{Player 2};
\node at($.5*(0-1)+.5*(0-4)$){Player 1};
% specifying payoffs
\node(payoff)[below]at(0-1-1){$\displaystyle\binom{-1}{+1}$};
\node[below]at(0-1-2){$\displaystyle\binom{+1}{-1}$};
\node[below]at(0-2-1){$\displaystyle\binom{-1}{+1}$};
\node[below]at(0-2-2){$\displaystyle\binom{-1}{+1}$};
\node[below]at(0-3-1){$\displaystyle\binom{+1}{-1}$};
\node[below]at(0-3-2){$\displaystyle\binom{+1}{-1}$};
\node[below]at(0-4-1){$\displaystyle\binom{+1}{-1}$};
\node[below]at(0-4-2){$\displaystyle\binom{-1}{+1}$};
\draw[<-](payoff)--+(-.9,0)node[left]
  {$\displaystyle\binom{\text{$1$'s Payoff}}{\text{$2$'s Payoff}}$};
\end{tikzpicture}
```
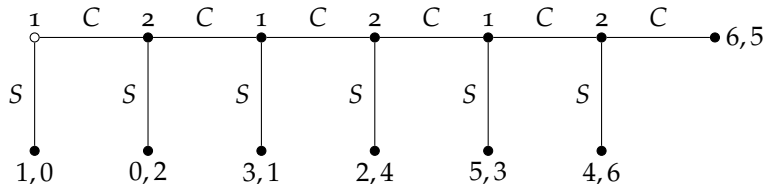
3.6 Centipede Game

Figure 8: Centipede Game

This is a replica of Osborne & Rubinstein (1994), Fig 107.1. Codes that produce Figure 8:

```
\begin{tikzpicture}[font=\footnotesize,scale=1]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % The Tree
  \node(0)[hollow node]{}
    child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
    child[grow=right]{node(1)[solid node]{}
      child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
      child[grow=right]{node(2)[solid node]{}
        child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
        child[grow=right]{node(3)[solid node]{}
          child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
          child[grow=right]{node(4)[solid node]{}
            child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
            child[grow=right]{node(5)[solid node]{}
              child[grow=down]{node[solid node]{}edge from parent node[left]{$S$}}
              child[grow=right]{node(6)[solid node]{}
              edge from parent node[above]{$C$}
              }
            edge from parent node[above]{$C$}
            }
          edge from parent node[above]{$C$}
          }
        edge from parent node[above]{$C$}
        }
      edge from parent node[above]{$C$}
      }
    edge from parent node[above]{$C$}
    };
  % Movers
```

```
\foreach \x in {0,2,4}
   \node[above]at(\x){1};
\foreach \x in {1,3,5}
   \node[above]at(\x){2};
% payoffs
\node[below]at(0-1){$1,0$};
\node[below]at(1-1){$0,2$};
\node[below]at(2-1){$3,1$};
\node[below]at(3-1){$2,4$};
\node[below]at(4-1){$5,3$};
\node[below]at(5-1){$4,6$};
\node[right]at(6){$6,5$};
\end{tikzpicture}
```
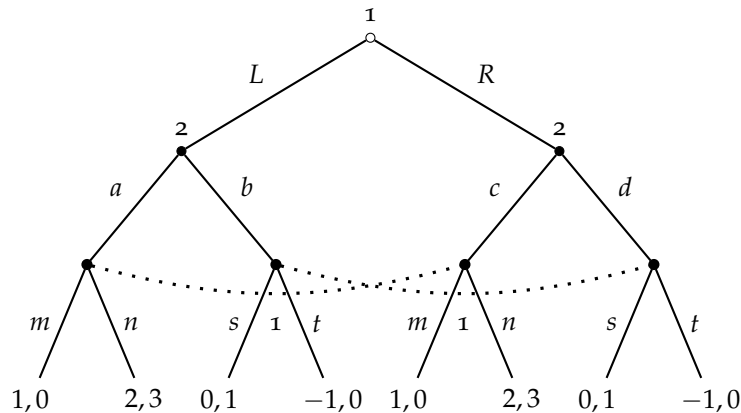
3.7 Curved Information Set

Figure 9: Game Tree with Curved Information Set

This is a replica of Fig 6 in Osborne's "Manual for `egameps.sty`". Codes that produce Figure 9:

```
\begin{tikzpicture}[font=\footnotesize,edge from parent/.style={draw,thick}]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=50mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=25mm]
    \tikzstyle{level 3}=[level distance=15mm,sibling distance=15mm]
  % The Tree
  \node(0)[hollow node]{}
    child{node[solid node]{}
      child{node[solid node]{}
        child{node[below]{$1,0$} edge from parent node[left]{$m$}}
        child{node[below]{$2,3$} edge from parent node[right]{$n$}}
        edge from parent node[above left]{$a$}
      }
      child{node[solid node]{}
        child{node[below]{$0,1$} edge from parent node(s)[left]{$s$}}
        child{node[below]{$-1,0$} edge from parent node(t)[right]{$t$}}
        edge from parent node[above right]{$b$}
      }
      edge from parent node[above left]{$L$}
    }
    child{node[solid node]{}
      child{node[solid node]{}
```

```
      child{node[below]{$1,0$} edge from parent node(m)[left]{$m$}}
      child{node[below]{$2,3$} edge from parent node(n)[right]{$n$}}
      edge from parent node[above left]{$c$}
    }
    child{node[solid node]{}
      child{node[below]{$0,1$} edge from parent node[left]{$s$}}
      child{node[below]{$-1,0$} edge from parent node[right]{$t$}}
      edge from parent node[above right]{$d$}
    }
    edge from parent node[above right]{$R$}
  };
% information sets
\draw[loosely dotted,very thick](0-1-1)to[out=-15,in=195](0-2-1);
\draw[loosely dotted,very thick](0-1-2)to[out=-15,in=195](0-2-2);
% movers
\node[above,yshift=2]at(0){1};
\foreach \x in {1,2} \node[above,yshift=2]at(0-\x){2};
\node at($.5*(s)+.5*(t)$){1};
\node at($.5*(m)+.5*(n)$){1};
\end{tikzpicture}
```
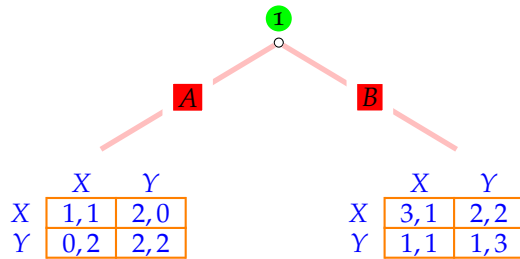
3.8 Colored and Hybrid Game Tree

Figure 10: Colored and Hybrid Game Tree

This is a replica of the figure on page 30 of Osborne's "Manual for `egameps.sty`". This figure requires the package sgame (documentation, download), which defines the game environment. Codes that produce Figure 10:

```
\begin{tikzpicture}[scale=1,font=\footnotesize,edge from parent/.style={line width=2,draw,pink}]
  % Two node styles: solid and hollow
    \tikzstyle{solid node}=[circle,draw,inner sep=1.2,fill=black];
    \tikzstyle{hollow node}=[circle,draw,inner sep=1.2];
  % Specify spacing for each level of the tree
    \tikzstyle{level 1}=[level distance=15mm,sibling distance=50mm]
    \tikzstyle{level 2}=[level distance=15mm,sibling distance=25mm]
  % The Tree
  \node(0)[hollow node]{}
    child{node{}
      edge from parent
      node[draw=white,line width=4,fill=red,inner sep=3.5]{\textcolor{black}{$A$}}
    }
    child{node{}
      edge from parent
      node[draw=white,line width=4,fill=red,inner sep=3.5,]{\textcolor{black}{$B$}}
    };
  % movers
  \node[above,circle,fill=green,inner sep=1,yshift=4]at(0){1};
  \node[below]at(0-1){
    \gamemathfalse
    \def\sgtextcolor{blue} % change text color
    \def\sglinecolor{orange} % change matrix color
    \arrayrulewidth.75pt
    \begin{game}{2}{2}
          & $X$   & $Y$\\
      $X$ & $1,1$ & $2,0$\\
      $Y$ & $0,2$ & $2,2$
```

```
      \end{game}
   };
   \node[below,xshift=-15]at(0-2){
      \gamemathfalse
      \def\sgtextcolor{blue} % change text color
      \def\sglinecolor{orange} % change matrix color
      \arrayrulewidth.75pt
      \begin{game}{2}{2}
            & $X$   & $Y$\\
         $X$ & $3,1$ & $2,2$\\
         $Y$ & $1,1$ & $1,3$
      \end{game}
   };
\end{tikzpicture}
```