

= Paterson 's worms =

Paterson 's worms are a family of cellular automata devised in 1971 by Mike Paterson and John Horton Conway to model the behaviour and feeding patterns of certain prehistoric worms . In the model , a worm moves between points on a triangular grid along line segments , representing food . Its turnings are determined by the configuration of eaten and uneaten line segments adjacent to the point at which the worm currently is . Despite being governed by simple rules the behaviour of the worms can be extremely complex , and the ultimate fate of one variant is still unknown .

The worms were studied in the early 1970s by Paterson , Conway and Michael Beeler , described by Beeler in June 1973 , and presented in November 1973 in Martin Gardner 's " Mathematical Games " column in Scientific American .

Electronic Arts ' game Worms ? [which see] is an interactive implementation of Patterson 's worms , where each time a worm has to turn in a way that it lacks a rule for , it stops and lets the user chooses a direction , which sets that rule for that worm .

= = History = =

Paterson 's worms are an attempt to simulate the behaviour of prehistoric worms . These creatures fed upon sediment at the bottom of ponds and avoided retracing paths they had already travelled because food would be scarce there but , because food occurred in patches , it was in the worm 's interest to stay near previous trails . Different species of worm had different innate rules regarding how close to travelled paths to stay , when to turn , and how sharp a turn to make . In 1969 Raup and Seilacher created computer simulations of the fossilized worm trails , and these simulations inspired Paterson and Conway to develop a simple set of rules to study idealized worms on regular grids .

Conway 's original model was a worm on an orthogonal grid but this produced only three different species of worm , all with rather uninteresting behaviour . Paterson considered worms on a triangular grid . Paterson 's worms were described by Beeler in a Massachusetts Institute of Technology AI Memo (# 290) and were presented in November 1973 in Martin Gardner 's " Mathematical Games " column in Scientific American , and later reprinted in Gardner 1986 . These simulations differed in approach from other cellular automata developed around the same time , which focused on cells and the relationships between them . Simple computer models such as these are too abstract to accurately describe the behaviour of the real creatures , but they do demonstrate that even very simple rules can give rise to patterns resembling their tracks .

= = Rules = =

The worm starts at some point of an infinite triangular grid . It starts moving along one of the six gridlines that meet at each point and , once it has travelled one unit of distance , it arrives at a new point . The worm then decides , based on the distribution of traversed and untraversed gridlines , what direction it will take . The directions are relative to the worm 's point of view . If the worm has not encountered this exact distribution before it may leave along any untraversed gridline . From then on , if it encounters that distribution again , it must move in the same way . If there are no untraversed gridlines available , the worm dies and the simulation ends .

= = Discussion = =

There are many different types of worm depending on which direction they turn when encountering a new type of intersection . The different varieties of worm can be classified systematically by assigning every direction a number and listing the choice made every time a new type of intersection is encountered .

The six directions are numbered as follows :

So direction 0 indicates the worm continues to travel straight ahead , direction 1 indicates the worm

will make a right turn of 60 ° and similarly for the other directions . The worm cannot travel in direction 3 because that is the gridline it has just traversed . Thus a worm with rule { 1 @,@ 0 @,@ 5 @,@ 1 } decides to travel in direction 1 the first time it has to make a choice , in direction 0 the next time it has to make a choice and so on . If there is only one available gridline , the worm has no choice but to take it and this is usually not explicitly listed .

A worm whose ruleset begins with 0 continues in a straight line forever . This is a trivial case , so it is usually stipulated that the worm must turn when it encounters a point with only uneaten gridlines . Furthermore , to avoid mirror @-@ image symmetrical duplicates , the worm 's first turn must be a right hand turn . A worm dies if it returns to its origin a third time , because there are then no untraversed edges available . Only the origin can be lethal to the worm .

There are 1 @,@ 296 possible combinations of worm rules . This can be seen by the following argument :

If the worm encounters a node with no eaten segments , other than the one it has just eaten , it can either make a sharp turn or a gentle one . This is the situation shown in the figure above .

If it encounters a node with one eaten segment , it can leave along any of the remaining four . Only the worm 's first return to the origin has this character .

For two eaten segments , the location of the eaten segments is important . There are four distinct combinations of eaten segments and approach directions , each of which offer a choice of three departure directions , making 81 different alternatives .

If the worm encounters three eaten segments , it must choose between the two remaining uneaten ones regardless of their distribution .

For four eaten segments , there is only one uneaten segment left and the worm must take it .

There are therefore $2 \times 4 \times 81 \times 2 = 1 @,@ 296$ different combinations of rules .

Many of these are mirror @-@ image duplicates of others , and others die before having to make all the choices in their ruleset , leaving 411 distinct species (412 if the infinite straight @-@ line worm is included) . 336 of these species eventually die . 73 patterns exhibit infinite behaviour , that is , they settle into a repeating pattern that does not return to the origin . A further two are strongly believed to be infinite and one remains unsolved . Eleven of the rules exhibit complicated behaviour . They do not die even after many billions of iterations , nor do they adopt an obviously infinite pattern . Their ultimate fate was unknown until 2003 when Benjamin Chaffin developed new methods of solving them . After many hours of computer time , nine of the eleven rules were solved , leaving the worms with rules { 1 @,@ 0 @,@ 4 @,@ 2 @,@ 0 @,@ 2 @,@ 0 } and { 1 @,@ 0 @,@ 4 @,@ 2 @,@ 0 @,@ 1 @,@ 5 } . The first of these was solved by Tomas Rokicki , who determined that it halts after 57 trillion timesteps , leaving only { 1 @,@ 0 @,@ 4 @,@ 2 @,@ 0 @,@ 1 @,@ 5 } unsolved . According to Rokicki , the worm is still active after $5 @.@ 2 \times 10^{19}$ timesteps . He used an algorithm based on Bill Gosper 's Hashlife to simulate the worms at extraordinary speeds . This behaviour is considerably more complex than the related rectangular grid worm , which has a longest path of only 16 segments .

It is possible for two different species of worm to produce the same path , though they do not necessarily traverse it in the same order . The most common path is also the shortest : the seven point " radioactivity symbol " . One example of this path is shown in the animated figure above . In total there are 299 different paths , and 209 of these are produced by just one species .

= Æthelwig =

Æthelwig (c . 1013 ? 16 February in either 1077 or 1078) was an Abbot of Evesham before and during the Norman Conquest of England . Born sometime around 1010 or 1015 , he was elected abbot in 1058 . Known for his legal expertise , he administered estates for Ealdred , the Bishop of Worcester prior to his election as abbot . After his election , he appears to have acted as Ealdred 's deputy , and was considered as a possible successor when Ealdred was elected Archbishop of York . Æthelwig worked during his abbacy to recover estates that had been lost to Evesham , as well as acquiring more estates .

After the Norman Conquest , in 1066 , Æthelwig was one of the few Englishmen trusted by the new King William the Conqueror , and was given authority over parts of western England . As part of his duties , he was a royal judge and held important prisoners . During the Harrying of the North in 1069 ? 1070 , Æthelwig gave aid to refugees from the north of England . He also helped the king in the rebellion of 1075 , preventing one of the rebels from joining the others . Æthelwig died on 16 February in either 1077 or 1078 , and was memorialised in a work on his life that was later incorporated in the *Chronicon Abbatiae de Evesham* , a 13th @-@ century history of the abbey and its abbots .

= = Early life and election as abbot = =

Æthelwig was probably born about 1010 to 1015 , and inherited a large amount of land from his family . He served as an administrator of the estates of Ealdred , the Bishop of Worcester , as well as those of Evesham Abbey . Æthelwig was also known as a legal expert . He was elected abbot in 1058 , and was blessed on 23 April 1058 , by Ealdred , who was the diocesan bishop for Evesham . He replaced the previous abbot , Mannig , who had become paralysed . One story has it that Ealdred asked King Edward the Confessor to give the abbacy to Æthelwig , another , in the *Chronicon de Abbatiae Evesham* , a history of Evesham Abbey , states that it was Mannig who asked the king to make the appointment . The *Chronicon* also states that the blessing took place at Gloucester , and that Ealdred was Archbishop at the time , although Ealdred did not become Archbishop of York until 1060 .

During Æthelwig 's abbacy , he appears to have acted as the deputy for Ealdred , as bishop of Worcester . In 1062 , he was one of the candidates to succeed Ealdred as bishop , when Ealdred was promoted to Archbishop of York , but Wulfstan was chosen instead . Æthelwig also served as a judge for King Edward the Confessor , at one point hearing a case at the royal court along with Wulfstan and Regenbald , the chancellor . The abbot also led military forces in battle , and served King Edward as an advisor .

Æthelwig 's relationship with Wulfstan , when Wulfstan was acting as the abbot 's diocesan bishop , appears to have been tense , for on the only recorded visitation by Wulfstan to Evesham during Æthelwig 's abbacy , Æthelwig was not there . Although in legal matters Wulfstan and Æthelwig were in conflict , personally , Æthelwig is said to have regarded Wulfstan as a father figure , and as the abbot 's confessor . The fact that the Evesham 's house chronicle appears to have been reworked after 1100 to gloss over embarrassing incidents of the abbots submitting to the bishops of Worcester makes evaluation of Æthelwig 's relations with his episcopal superiors more difficult .

During Edward 's reign , Æthelwig worked to recover some of the abbey 's estates that had been granted to others in the past but had not been returned to the abbey 's custody . He managed to restore the abbey 's possession of a number of these lost estates . A large section of the description of the abbot 's life in the *Chronicon* is concerned with a listing of estates that Æthelwig acquired or recovered . The estates listed were in the counties of Worcestershire , Warwickshire , and Gloucestershire .

= = After the Conquest = =

After the Norman Conquest , Æthelwig was trusted by the new king , William the Conqueror , and given some administrative duties . Æthelwig was one of a very small number of native Englishmen trusted by the king , which group included Ealdred and Wulfstan . Probably in 1069 , Æthelwig was given authority in the former lands of the Mercian kingdom . After the deposition of Godric , the abbot of Winchcombe Abbey in 1070 , Æthelwig served as his jailor . In 1072 , Æthelwig was acting as a royal judge in the western part of England . During the rebellion of 1075 , Æthelwig kept Roger de Breteuil , the Earl of Hereford , one of the rebels , from joining up with the other rebels . In this action , Æthelwig was assisted by Wulfstan , as well as the sheriff of Worcestershire , Urse d 'Abetot . Æthelwig also took the opportunity after the Norman Conquest to acquire more lands , obtaining 36 estates by redeeming loans . Æthelwig used his knowledge of English law not only on his own

account , but to aid the new Norman ecclesiastics , such as Lanfranc , the Archbishop of Canterbury , and Serlo , the Abbot of Gloucester . A number of English landowners commended themselves into Æthelwig 's care after the Conquest , and this led to conflicts over who owned the lands after Æthelwig 's death .

Although Æthelwig was known for his loyalty to King William , he had an uncle who held land at Witton who died fighting for King Harold Godwinson , probably at the Battle of Stamford Bridge . While abbot , even after the Conquest , Æthelwig continued to build and ornament his abbey in the Anglo -Saxon style , not the Norman Romanesque which was being used in many of the other churches and abbeys . Besides his administrative and legal duties , Æthelwig was known for his care for the sick and the poor , as well as lepers . After the Harrying of the North by King William in 1069 ? 1070 , Æthelwig offered shelter to refugees from the ravaged areas . The Chronicon states that Æthelwig offered aid to the refugees because of his charitable nature , but it is possible that it was also part of his royal duties in western England .

Æthelwig also administered Winchcombe Abbey for a number of years , at first from 1066 to 1069 when a Norman monk was appointed abbot , and then again from 1075 until Æthelwig 's death . Hemming , a medieval monastic writer from Worcester Priory , wrote of Æthelwig that he " surpassed everyone by his intelligence , his shrewdness and his knowledge of worldly law " . The Chronicon reports that Æthelwig suffered from gout , and states that it was the cause of his death .

Æthelwig died in either 1077 or 1078 . The Chronicon gives his death date as 16 February 1077 , but it is unclear if the Chronicon began its years on 1 January or in March , so the date could be 1077 or 1078 .

= = Writing about Æthelwig = =

A near -contemporary account of Æthelwig 's life , or Vita , is included in the Chronicon Abbatiae de Evesham , the monastic chronicle for Evesham Abbey . This was a 13th -century work by Thomas of Marlborough , which was written to bolster the Evesham 's case for exemption from the jurisdiction of the Bishops of Worcester , in whose diocese Evesham was . In order to do this , Thomas incorporated earlier works dealing with Evesham 's history , including the work on Æthelwig . However , because of Thomas ' purpose in composing the Chronicon , he probably altered some of the texts he included , and it appears that the life of Æthelwig was first incorporated into a complete history of the abbey and then that composite work was adapted by Thomas into his Chronicon . The main evidence for this is internal stylistic evidence , where the Æthelwig material is stylistic uniform with other material dating to prior to 1077 , with information after 1077 forming a separate writing style .

The historian R. R. Darlington argued that the Vita was written right after Æthelwig 's death , but another historian , David Knowles , wrote that it probably was written about 1110 , possibly by the prior of Evesham , Dominic . Antonia Gransden , another historian , agrees with Darlington , and finds it more likely to have been written shortly after Æthelwig 's death . The work itself is not a hagiography , in that it doesn 't attribute any miracles to Æthelwig , and instead is a mix of charters and narratives . Nor does it give any details on Æthelwig 's early life or his selection as abbot . A large portion of the work is a detailed list of lands acquired by Æthelwig for the abbey , and concludes with a short description of the abbot 's death .