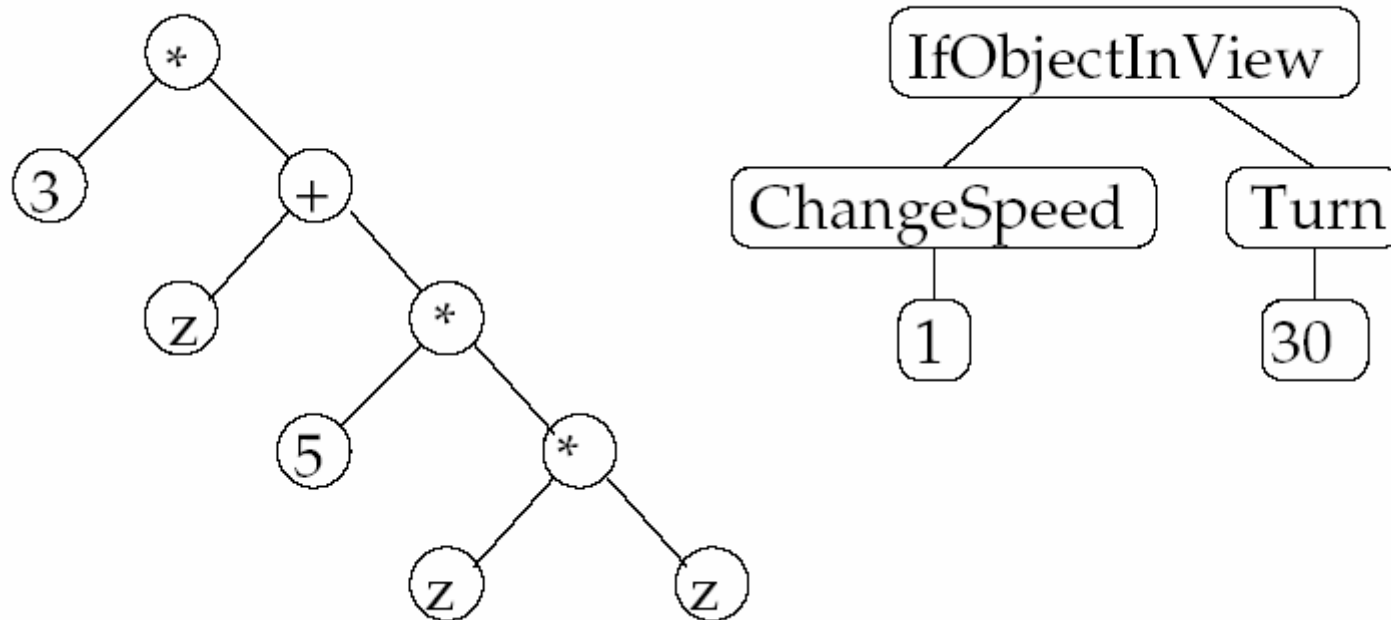
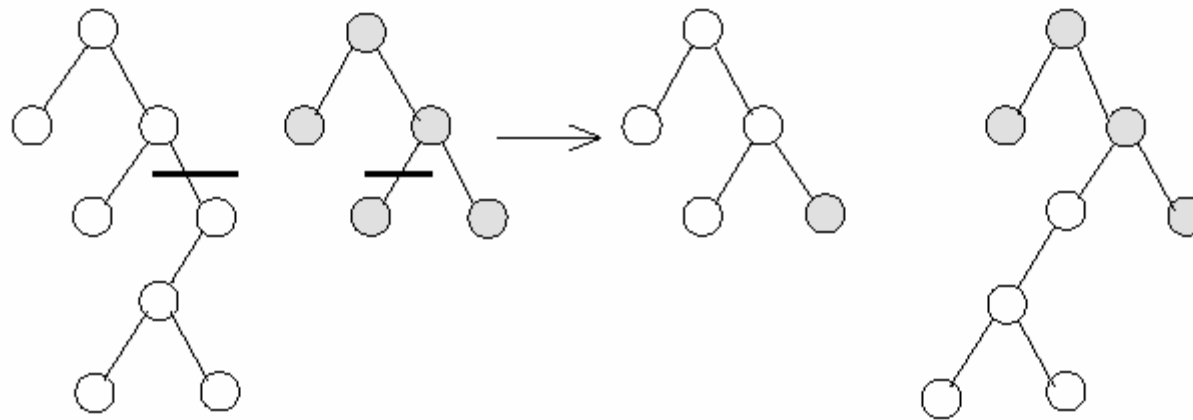
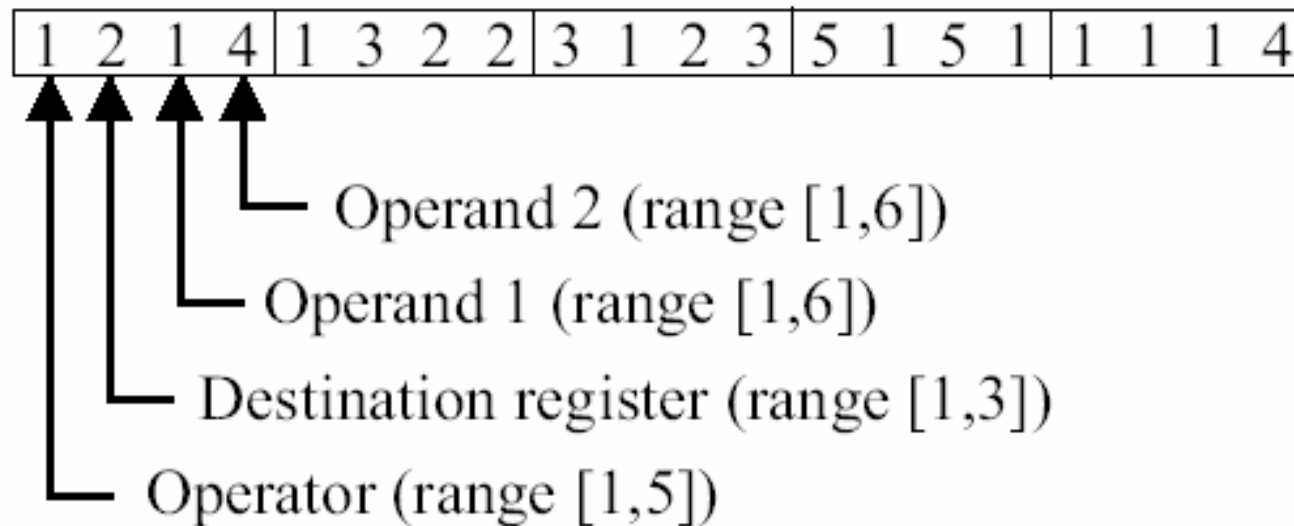






| Instruction    | Description             | Instruction        | Description         |
|----------------|-------------------------|--------------------|---------------------|
| Addition       | $r_i := r_j + r_k$      | Sine               | $r_i := \sin r_j$   |
| Subtraction    | $r_i := r_j - r_k$      | Cosine             | $r_j := \cos r_j$   |
| Multiplication | $r_i := r_j \times r_k$ | Square             | $r_i := r_j^2$      |
| Division       | $r_i := r_j / r_k$      | Square root        | $r_i := \sqrt{r_j}$ |
| Exponentiation | $r_i := e^{r_j}$        | Conditional branch | if $r_i > r_j$      |
| Logarithm      | $r_i := \ln r_j$        | Conditional branch | if $r_i \leq r_j$   |

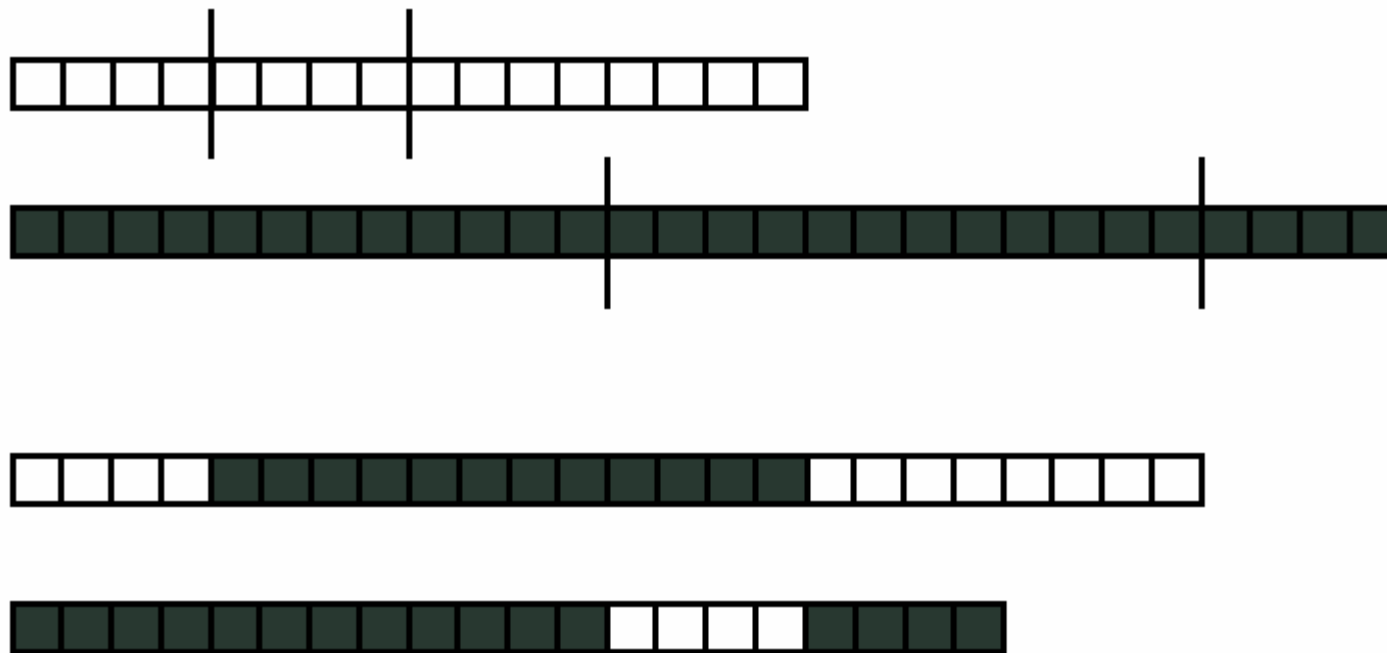
**Table 2.5:** Examples of typical LGP operators. Note that the operands can be either variable registers or constant registers.



**Figure 2.31:** *An example of an LGP chromosome.*

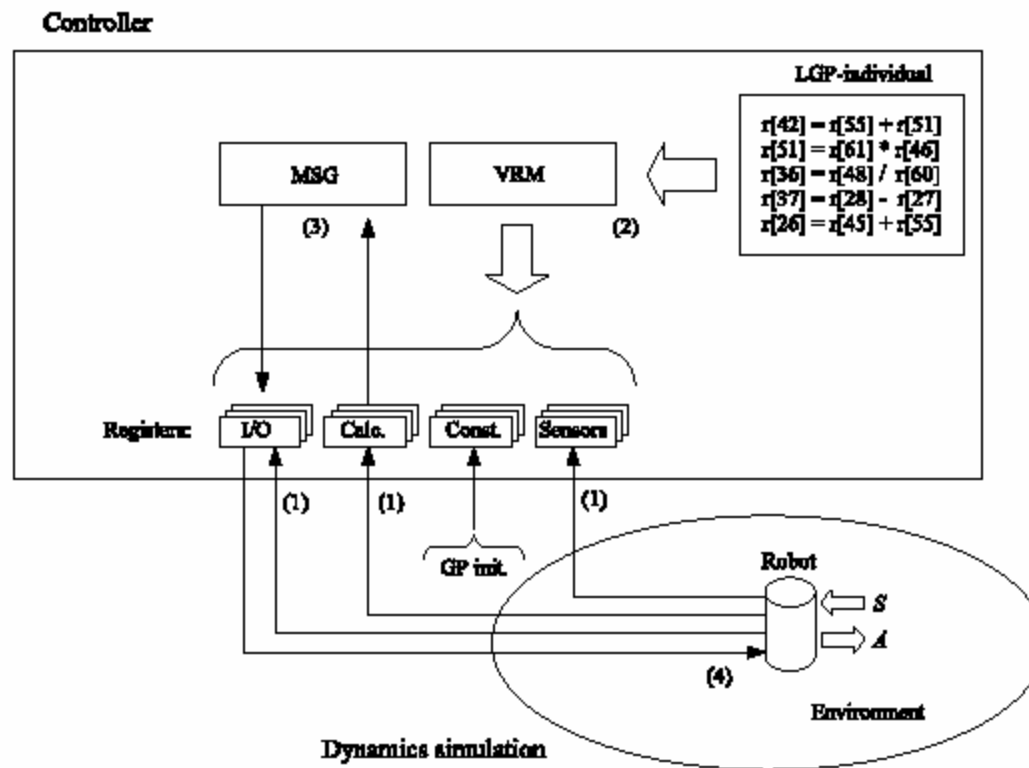
| Genes      | Instruction             | Result                      |
|------------|-------------------------|-----------------------------|
| 1, 2, 1, 4 | $r_2 := r_1 + c_1$      | $r_1 = 1, r_2 = 2, r_3 = 0$ |
| 1, 3, 2, 2 | $r_3 := r_2 + r_2$      | $r_1 = 1, r_2 = 2, r_3 = 4$ |
| 3, 1, 2, 3 | $r_1 := r_2 \times r_3$ | $r_1 = 8, r_2 = 2, r_3 = 4$ |
| 5, 1, 5, 1 | if ( $r_1 > c_2$ )      | $r_1 = 8, r_2 = 2, r_3 = 4$ |
| 1, 1, 1, 4 | $r_1 := r_1 + c_1$      | $r_1 = 9, r_2 = 2, r_3 = 4$ |

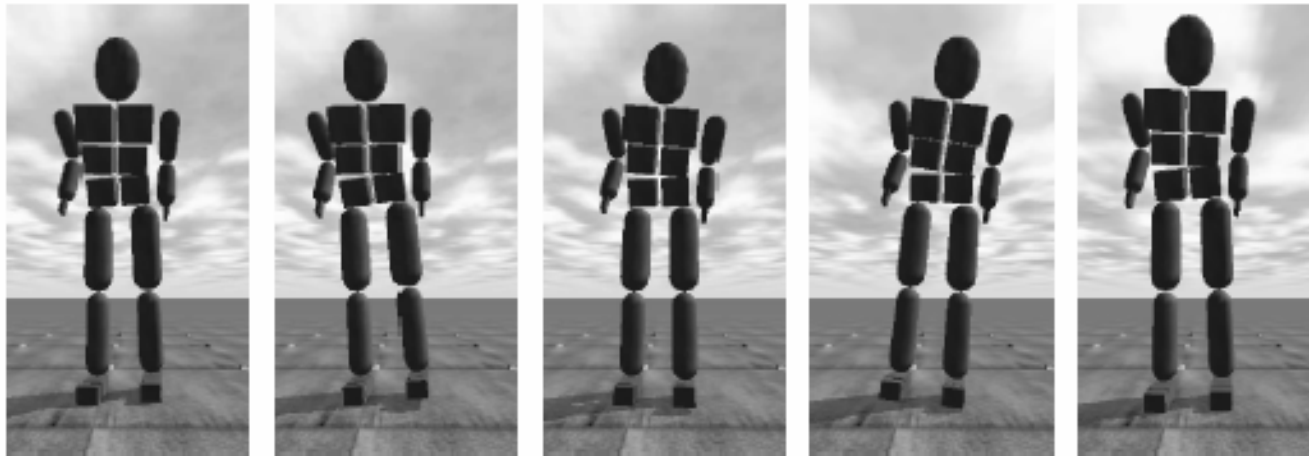
**Table 2.6:** Evaluation of the chromosome shown in Fig. 2.31, in a case where the input register  $r_1$  was initially assigned the value 1. The variable registers  $r_2$  and  $r_3$  were both set to 0, and the constant registers were set as  $c_1 = 1, c_2 = 3, c_3 = 10$ . The first instruction (top line) is decoded from the first four genes in the chromosome etc. The resulting output was taken as the value contained in  $r_1$  at the end of the calculation.



**Figure 2.32:** *An illustration of crossover in LGP. The two parent chromosomes are shown in the upper part of the figure, and the two offspring chromosomes are shown below. Note that two crossover points are selected in each chromosome.*

## Example: LGP for bipedal gaits





(a)

(b)

(c)

(d)

(e)

