

## procedure INTELLIGENT TRIAL AND ERROR ALGORITHM

Before the mission:

CREATE BEHAVIOR-PERFORMANCE MAP (VIA THE MAP-ELITES ALGORITHM IN SIMULATION)

**while** In mission **do**

**if** Significant performance fall **then**

ADAPTATION STEP (VIA M-BOA ALGORITHM)

## procedure MAP-ELITES ALGORITHM

$(\mathcal{P} \leftarrow \emptyset, \mathcal{C} \leftarrow \emptyset)$   $\triangleright$  Creation of an empty behavior-performance map (empty  $N$ -dimensional grid).

**for** iter = 1  $\rightarrow$   $I$  **do**  $\triangleright$  Repeat during  $I$  iterations (here we choose  $I = 40$  million iterations).

**if** iter < 400 **then**

$\mathbf{c}' \leftarrow \text{random\_controller}()$   $\triangleright$  The first 400 controllers are generated randomly.

**else**  $\triangleright$  The next controllers are generated using the map.

$\mathbf{c} \leftarrow \text{random\_selection}(\mathcal{C})$   $\triangleright$  Randomly select a controller  $c$  in the map.

$\mathbf{c}' \leftarrow \text{random\_variation}(\mathbf{c})$   $\triangleright$  Create a randomly modified copy of  $c$ .

$\mathbf{x}' \leftarrow \text{behavioral\_descriptor}(\text{simu}(\mathbf{c}'))$   $\triangleright$  Simulate the controller and record its behavioral descriptor.

$p' \leftarrow \text{performance}(\text{simu}(\mathbf{c}'))$   $\triangleright$  Record its performance.

**if**  $\mathcal{P}(\mathbf{x}') = \emptyset$  or  $\mathcal{P}(\mathbf{x}') < p'$  **then**  $\triangleright$  If the cell is empty or if  $p'$  is better than the current stored performance.

$\mathcal{P}(\mathbf{x}') \leftarrow p'$   $\triangleright$  Store the performance of  $\mathbf{c}'$  in the behavior-performance map according to its behavioral descriptor  $\mathbf{x}'$ .

$\mathcal{C}(\mathbf{x}') \leftarrow \mathbf{c}'$   $\triangleright$  Associate the controller with its behavioral descriptor.

**return** behavior-performance map ( $\mathcal{P}$  and  $\mathcal{C}$ )

## procedure M-BOA (MAP-BASED BAYESIAN OPTIMIZATION ALGORITHM)

$\forall \mathbf{x} \in \text{map}$ :  $\triangleright$  Initialisation.

$P(f(\mathbf{x})|\mathbf{x}) = \mathcal{N}(\mu_0(\mathbf{x}), \sigma_0^2(\mathbf{x}))$   $\triangleright$  Definition of the Gaussian Process.

where

$\mu_0(\mathbf{x}) = \mathcal{P}(\mathbf{x})$   $\triangleright$  Initialize the mean prior from the map.

$\sigma_0^2(\mathbf{x}) = k(\mathbf{x}, \mathbf{x}) + \sigma_{noise}^2$   $\triangleright$  Initialize the variance prior (in the common case,  $k(\mathbf{x}, \mathbf{x}) = 1$ ).

**while**  $\max(\mathbf{P}_{1:t}) < \alpha \max(\mu_t(\mathbf{x}))$  **do**  $\triangleright$  Iteration loop.

$\chi_{t+1} \leftarrow \arg \max_{\mathbf{x}} (\mu_t(\mathbf{x}) + \kappa \sigma_t(\mathbf{x}))$   $\triangleright$  Select next test (argmax of acquisition function).

$P_{t+1} \leftarrow \text{performance}(\text{physical\_robot}(\mathcal{C}(\chi_{t+1})))$   $\triangleright$  Evaluation of  $\mathbf{x}_{t+1}$  on the physical robot.

$P(f(\mathbf{x})|\mathbf{P}_{1:t+1}, \mathbf{x}) = \mathcal{N}(\mu_{t+1}(\mathbf{x}), \sigma_{t+1}^2(\mathbf{x}))$   $\triangleright$  Update the Gaussian Process.

where

$\mu_{t+1}(\mathbf{x}) = \mathcal{P}(\mathbf{x}) + \mathbf{k}^\top \mathbf{K}^{-1} (\mathbf{P}_{1:t+1} - \mathcal{P}(\chi_{1:t+1}))$   $\triangleright$  Update the mean.

$\sigma_{t+1}^2(\mathbf{x}) = k(\mathbf{x}, \mathbf{x}) + \sigma_{noise}^2 - \mathbf{k}^\top \mathbf{K}^{-1} \mathbf{k}$   $\triangleright$  Update the variance.

$\mathbf{K} = \begin{bmatrix} k(\chi_1, \chi_1) & \cdots & k(\chi_1, \chi_{t+1}) \\ \vdots & \ddots & \vdots \\ k(\chi_{t+1}, \chi_1) & \cdots & k(\chi_{t+1}, \chi_{t+1}) \end{bmatrix} + \sigma_{noise}^2 \mathbf{I}$   $\triangleright$  Compute the observations' correlation matrix.

$\mathbf{k} = \begin{bmatrix} k(\mathbf{x}, \chi_1) & k(\mathbf{x}, \chi_2) & \cdots & k(\mathbf{x}, \chi_{t+1}) \end{bmatrix}$   $\triangleright$  Compute the  $\mathbf{x}$  vs. observation correlation vector.