

A faint, grayscale background image of a human ribcage, showing the ribs and the underlying lung area. The image is centered and occupies most of the frame.

Annexe

```
import json
from pathlib import Path
from typing import Any, Optional, TypeVar
```

```
import cv2
import matplotlib.pyplot as plt
import numpy as np
from nptyping import NDArray
from rich.progress import Progress
```

```
from angles import display_lines, get_lines_probabilistic
from utils import *
```

detect.py

Traitements basiques et
détection des bords

```
def is_broken(angles: list[float], ε: float = 10) → bool:
    """
    If the maximum offset with a vertical angle is less than ε for all angles, the bone is not broken
    """
    τ = 2 * np.pi
    deg = lambda rad: rad / τ * 180
    print("[ " + " ".join(f"{int(deg(angle))}" for angle in angles) + " ]")
    return max(map(deg, angles)) ≥ ε
```

```
def is_white(pixel: float) → bool:
    return pixel > 0.75
```

```
def center_of(image: np.ndarray) → np.ndarray:
    # return image[:, len(image[0])//4: -len(image[0])//4]
    return image
```

```
def contrast_of(image: np.ndarray) → float:
    if len(image.shape) == 2:
        return image.std()
    return cv2.cvtColor(image, cv2.COLOR_BGR2GRAY).std()
```

```
def boost_contrast(image: np.ndarray) → np.ndarray:
    return 4 * image
```

```
def grayscale_of(image: NDArray[Any, Any, 3]) → NDArray[Any, Any]:
    return cv2.cvtColor(image, cv2.COLOR_BGR2HSV)[: , : , 2]
```

```
def brightness_of(image: Union[NDArray[Any, Any, 3], NDArray[Any, Any]]) → float:
    # RGB
    if len(image.shape) == 3:
        image = grayscale_of(image)
    return mean(flatten_2D(image))
```

```
def detect_edges(
    image: Union[NDArray[Any, Any, 3], NDArray[Any, Any]],
    low: int,
    high: int,
    σ: int = 3,
    blur: float = 0,
) → tuple[NDArray[Any, Any, 3], NDArray[Any, Any]]:
    """
    Détecte les bords d'une image, en utilisant—si blur ≠ 0—un filtre bilatéral avec un σ_color =
    σ_space = blur.
    """
    σ, low, high = map(int, (σ, low, high))

    if len(image.shape) == 2:
        image = cv2.cvtColor(image, cv2.COLOR_GRAY2BGR)

    if blur:
        # image = cv2.bilateralFilter(image, d=5, sigmaColor=blur, sigmaSpace=blur)
        image = cv2.blur(image, (blur, blur))

    edges = cv2.Canny(image, low, high, apertureSize=σ, L2gradient=True)
    return image, edges
```

```
def save_figure(image_path: Path, save: Optional[Path] = None):
    image = cv2.imread(str(image_path))
    print(f"contrast is {contrast_of(image)}")
    original, edges = detect_edges(image, low=40, high=120, blur=3)
    lines = list(get_lines_probabilistic(center_of(edges), gap=5, length=20))
    if not lines:
        print(f"error: no lines detected for {image}")
        return
    broken = is_broken([angle for _, _, angle in lines])
    fig, ax = plt.subplots(1, 2, sharex=True, sharey=True)
    fig.suptitle(
        f"Détecté comme {'cassé' if broken else 'sain'}\n"
        f"cont: {contrast_of(image)} lum: {brightness_of(image)}\n"
        f"tilt: {image_tilt(lines)/(2*np.pi)*180}° #segments: {len(lines)}\n"
        f"outlum: {brightness_of(center_of(edges))} lumratio:
    {brightness_of(center_of(edges))/brightness_of(image)}"
    )
    ax[0].imshow(original)
    # ax[1].imshow(edges)
    display_lines(ax[1], center_of(edges), lines)

    if save:
        plt.savefig(str(save))
    else:
        plt.show()

    print(
        f'{image_path}: Detected as {"broken" if broken else "healthy"}',
        end="\n\n",
    )
```

```
if __name__ == "__main__":
    with Progress() as bar:
        files = list(Path("datasets/various").glob("*.png"))
        task = bar.add_task("[blue]Processing", total=len(files))
        for testfile in files:
            save_figure(testfile, save=Path("line-detection") / testfile.name)
            bar.advance(task)
```

```
import pathlib
from typing import Iterable, Optional
from math import sqrt
import numpy as np
```

```
 $\tau = 2 * \text{np.pi}$ 
```

```
import matplotlib.pyplot as plt
from skimage.transform import (hough_line, hough_line_peaks,
                              probabilistic_hough_line)
```

```
def norm(a: tuple[int, int], b: tuple[int, int]) → float:
    return sqrt((a[0] - b[0])**2 + (a[1] - b[1])**2)
```

```
def get_lines_probabilistic(
    edges: np.ndarray, length: int = 5, gap: int = 3, minimum_length: float = 0
) → Iterable[tuple[tuple[int, int], tuple[int, int], float]]:
    """
```

```
    Return value:
    list of (start point, end point, angle with the vertical projection in
    radians)
    """
```

```
    for beginning, end in probabilistic_hough_line(
        edges, threshold=10, line_length=length, line_gap=gap
    ):
        x0, y0 = beginning
        x1, y1 = end
        # CAH
        angle = np.arccos(abs(y1 - y0) / np.sqrt((x1 - x0) ** 2 + (y1 - y0) **
2))
```

```
    if norm(beginning, end) ≥ minimum_length:
        yield beginning, end, angle
```

angles.py
Détection des lignes et
calcul des angles

```
def unique_angles(ε: float, lines: Iterable[tuple[tuple[int, int], tuple[int,
int], float]]) → set[float]:
    """
```

```
    Return list of unique angles. Two angles are considered equal if they are
    less than ε appart from each other.
    """
```

```
    angles = set()
    for _, _, angle1 in lines:
        for _, _, angle2 in lines:
            if abs(angle1 - angle2) > ε:
                angles.add(angle1)
    return angles
```

```
def display_lines(
    ax,
    image: np.ndarray,
    lines: list[tuple[tuple[int, int], tuple[int, int], float]],
    probabilistic: bool = True,
    save: Optional[str] = None,
):
    """
    Display lines on top of image with matplotlib
    """
    plt.imshow(image, cmap="gray")
    midway = lambda p1, p2: ((p1[0] + p2[0]) / 2, (p1[1] + p2[1]) / 2)
    if probabilistic:
        counter = 0
        # for beginning, end, angle in lines[5:6]:
        for (x0, y0), (x1, y1), angle in lines:
            ax.plot([x0, x1], [y0, y1], color="red")
            ax.plot([x0, x0], [y0, y1], color="blue")
            ax.text(
                *midway((x0, y0), (x1, y1)), f"{int(angle*180/tau)}°",
                color="white"
            )
            counter += 1
    else:
        for *point, angle in lines:
            ax.axline(point, slope=angle)
            ax.scatter(*point)

    ax.set_xlim(0, image.shape[1])
    ax.set_ylim(image.shape[0], 0)
    if save:
        plt.savefig(save)
```



```

from math import sqrt
from abc import ABCMeta, abstractmethod
from typing import Iterable, Union, TypeVar, Callable, Any

```

```

def mean(o: Iterable[Union[float, int]]) → float:
    values = list(o)
    return sum(values) / len(values)

```

```

def flatten_2D(o: Iterable):
    flat = []
    for row in o:
        for item in row:
            flat.append(item)
    return flat

```

needed to remove pylint(cell-var-from-loop), see
<https://stackoverflow.com/a/67928238/9943464>

```

def access(o, key):
    return o.get(key)

```

```

def norm(vector):
    return sqrt(sum(map(lambda x: x ** 2, vector)))

```

```

def roughly_equals(ε=0.01) → Callable[..., bool]:
    def _(a, *b):
        return any(abs(a - b_) < ε for b_ in b)

```

```

    return _

```

```

T = TypeVar("T", bound=Union[float, int])
def clip(minimum: T, maximum: T, o: T) → T:
    return max(minimum, min(maximum, o))

```

utils.py
 Fonctions diverses utiles à
 l'ensemble du programme

```

T = TypeVar("T")
def partition(o: Iterable[T], layout: Union[list[int], tuple[int]]) →
list[list[T]]:
    """

```

Chunks o into chunks of sizes given by layout.

```

>>> partition([1, 2, 3, 4, 5, 6, 7, 8, 9], (3, 3, 3))
[[1, 2, 3], [4, 5, 6], [7, 8, 9]]

```

```

>>> partition([1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12], (4, 4, 4))
[[1, 2, 3, 4], [5, 6, 7, 8], [9, 10, 11, 12]]

```

```

>>> partition([1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12], (6, 2, 4))
[[1, 2, 3, 4, 5, 6], [7, 8], [9, 10, 11, 12]]
"""

```

can't use [[]] * len(layout) as all sublists will be views of the
 same sublist

```

partitions = []
for _ in layout:
    partitions.append([])

```

```

index_in_partition = 0
current_partition = 0

```

```

for item in o:
    partitions[current_partition].append(item)
    if index_in_partition == layout[current_partition] - 1:
        current_partition += 1
        index_in_partition = 0
    else:
        index_in_partition += 1

```

```

return partitions

```

```
from datetime import datetime
import matplotlib.pyplot as plt
import random
import inspect
import json
from pathlib import Path
from typing import *
import textwrap
```

rl_environment.py ^{1/2}

Environnement pour l'apprentissage par renforcement

```
import cv2
import gym
import numpy as np
from gym import spaces
from nptyping import NDArray
from numpy import array
from rich import print
from angles import get_lines_probabilistic, unique_angles, display_lines
```

```
from detect import brightness_of, contrast_of, detect_edges, grayscale_of
from utils import roughly_equals, clip
```

```
class EdgeDetectionEnv(gym.Env):
    metadata = {"render_modes": ["human", "rgb_array"], "render_fps": 4}
```

```
    def pick_from_dataset(self) → NDArray:
        self.current_image_name = random.choice(self.dataset)
        print(f"picking {self.current_image_name}")
        return self.preprocess(cv2.imread(self.current_image_name))
```

```
    @property
    def saw_everything(self) → bool:
        return len(self.seen_images) == len(self.dataset)
```

```
    @property
    def dataset_size(self) → int:
        return len(self.dataset)
```

```
    def preprocess(self, image: NDArray) → NDArray:
        """
        Resize the image to the biggest dimensions of the dataset
        """
        width, height = image.shape[:2]
        if width == self.image_dimensions[0] and height ==
self.image_dimensions[1]:
            return image
```

```
        print(f"preprocess: resizing: {width}x{height} →
{self.image_dimensions}")
        return cv2.resize(image, self.image_dimensions)
```

```
    def biggest_dimensions(self, dataset: list[str]) → Tuple[int, int]:
        biggest_width = biggest_height = 0
        for image in dataset:
            width, height = cv2.imread(image).shape[:2]
            if width > biggest_width:
                biggest_width = width
            if height > biggest_height:
                biggest_height = height
        return biggest_width, biggest_height
```

```
    def done(self) → bool:
        return self.steps_count_for_current_image >
self.max_steps_for_single_image or (int(brightness_of(self.edges)) in
range(*self.acceptable_brightness_range) and self.segments_count in
range(*self.acceptable_segments_count_range))
```

```
    def save_settings(self, agent_name: str, into: Path):
        # Used to encode int64 and other numpy number types
        def numpy_encoder(object):
            if isinstance(object, np.generic):
                return object.item()

        assert self.current_image_name is not None
        save_as = into / agent_name / Path(self.current_image_name).stem
        save_as.parent.mkdir(parents=True, exist_ok=True)
        Path(f"{save_as}--info.json").write_text(json.dumps(self.info,
default=numpy_encoder, indent=2))
        cv2.imwrite(f"{save_as}--source.png", self.source)
        cv2.imwrite(f"{save_as}--edges.png", self.edges)
        cv2.imwrite(f"{save_as}--original-source.png", self.original_source)
        _, ax = plt.subplots()
        display_lines(ax, self.edges, self.segments, probabilistic=True,
save=f"{save_as}--lines.png")
```

```
    @property
    def action_space_shape(self) → int:
        return sum(v[0] for v in self.action_space_layout.values())
```

```
    def __init__(
        self,
        render_mode: Union[str, None],
        acceptable_brightness_range: Tuple[int, int],
        acceptable_segments_count_range: Tuple[int, int],
        dataset: Path,
        max_thresholds_increment: int = 5,
        max_brightness_increment: int = 3,
        max_blur_value: int = 30,
        step_blur_value: int = 1,
        max_steps_for_single_image: int = 10_000,
    ):
        assert render_mode is None or render_mode in
self.metadata["render_modes"]
```

```
        self.dataset = [str(f) for f in dataset.iterdir() if f.is_file()]
        self.seen_images = set()
        self.unique_segment_angles = set()
        self.current_image_name = None
        self.thresholds = [100, 100]
        self.brightness_boost = 0
        self.segments = []
        self.blur = 0
        self.max_steps_for_single_image = max_steps_for_single_image
        self.segments_count = None
        self.contrast_multiplier = 1
        self.acceptable_brightness_range = acceptable_brightness_range
        self.acceptable_segments_count_range = acceptable_segments_count_range
        self.image_dimensions = self.biggest_dimensions(self.dataset)
        self.max_increment = max_thresholds_increment
        self.max_contrast_increment = 1
        self.max_brightness_increment = max_brightness_increment
        self.max_blur_value = max_blur_value // step_blur_value
        self.step_blur_value = step_blur_value
        self.steps_count_for_current_image = 0
        self.last_winning_edges = array([])
        self.last_winning_thresholds = [None, None]
```

```
        pixels_space = lambda width, height: spaces.Box(low=array([0, 0]),
high=array([width, height]), dtype=np.int16)
```

```
        # we stick the two images horizontally instead of adding a third
dimension (2*width, height) instead of (2, width, height)
        self.observation_space_shape = (
            self.image_dimensions[0],
            self.image_dimensions[1],
        )
        # self.observation_space.shape gives (2,) instead of (width, height)
        self.observation_space = pixels_space(*self.observation_space_shape)
```

```
        # key: [size, offset]
        self.action_space_layout = {
            "high_threshold": [2 * max_thresholds_increment, -
max_thresholds_increment],
            "low_threshold": [2 * max_thresholds_increment, -
max_thresholds_increment],
            "contrast": [2*self.max_contrast_increment, -
self.max_contrast_increment],
            "brightness": [
                2 * self.max_brightness_increment,
                -self.max_brightness_increment,
            ],
            "blur": [self.max_blur_value, 0],
        }

        self.action_space = spaces.Dict(
            {k: spaces.Discrete(size, start=offset) for k, (size, offset) in
self.action_space_layout.items()})
```

```
        print(f"Initialized action space with layout {self.action_space_layout}")
```

```
        if render_mode == "human":
            import pygame

            pygame.init()
            pygame.display.init()
            self.window = pygame.display.set_mode(self.image_dimensions)
            self.clock = pygame.time.Clock()
```

```
        # self.renderer = Renderer(render_mode, self._render_frame)
```

```
    @property
    def observation(self) → NDArray:
        return array([self.source,
self.edges]).reshape(*self.observation_space_shape)
```

```
    def reward(self, brightness: float) → float:
        lo, hi = self.acceptable_brightness_range
```

```
        if brightness in self.acceptable_brightness_range:
            return 1
```

```
        offset = abs(brightness - (lo if brightness < lo else hi))
        width = abs((0 - lo) if brightness < lo else (255 - hi))
```

```
        reward = 1 - (offset / width)
```

```
        if reward == 1 and self.segments_count is not None:
            lo, hi = self.acceptable_segments_count_range
            offset = abs(self.segments_count - (lo if self.segments_count < lo
else hi))
            # en supposant segments count ∈ [0, 10_000]
            width = abs((0 - lo) if self.segments_count < lo else (10_000 - hi))
            return clip(0, 1, 0.25 + (1 - offset / width))
```

```
        return reward
```


rl_environment.py 2/2

Environnement pour l'apprentissage par renforcement

```
@property
def info(self) -> Dict[str, Any]:
    return {
        "at": f"{datetime.now():%Y-%m-%dT%H:%M:%S}",
        "source": {
            "brightness": brightness_of(self.source),
            "contrast": contrast_of(self.source),
            # "original": self.original_source,
            "name": self.current_image_name,
        },
        "edges": {
            "brightness": brightness_of(self.edges),
            "contrast": contrast_of(self.edges),
        },
        "segments": {
            "count": self.segments_count,
            "angles": list(self.unique_segment_angles),
        },
        "settings": {
            "high_threshold": self.thresholds[0],
            "low_threshold": self.thresholds[1],
            "contrast_multiplier": self.contrast_multiplier,
            "brightness_boost": self.brightness_boost,
            "bilateral_blur_sigmas": self.blur,
        },
    }

def reset(self, seed=None, return_info=False):
    super().reset(seed=seed)
    # Pick a random bone radio image from the set
    self.source, self.edges = detect_edges(self.pick_from_dataset(), low=seed
or 50, high=seed or 50)
    self.source = grayscale_of(self.source)
    self.original_source = self.source.copy()
    if self.steps_count_for_current_image <= self.max_steps_for_single_image:
        self.seen_images.add(self.current_image_name)
    self.steps_count_for_current_image = 0

    return (self.observation, self.info) if return_info else self.observation

def step(self, action: OrderedDict, ε):
    print(f"with {dict(**action)}", end=" ")

    self.thresholds[0] = clip(20, 150, self.thresholds[0] +
action["high_threshold"])
    self.steps_count_for_current_image += 1
    self.thresholds[1] = clip(20, 150, self.thresholds[1] +
action["low_threshold"])
    self.blur = action["blur"]
    self.ε = ε
    self.contrast_multiplier = 1 + clip(0, 5, self.contrast_multiplier*10 - 1
+ action["contrast"]) / 10
    self.brightness_boost = clip(0, 30, self.brightness_boost +
action["brightness"])
    self.source = np.clip(
        self.original_source.astype("int16") * self.contrast_multiplier +
self.brightness_boost,
        # self.source.astype("int16") + action["brightness"],
    ).astype("uint8")
    blurred_source, self.edges = detect_edges(self.source, *self.thresholds,
blur=self.blur * self.step_blur_value)
    self.source = grayscale_of(blurred_source)
    edges_brightness = brightness_of(self.edges)
```

```
if roughly_equals(0.001)(edges_brightness, 0, 255):
    print("pullup", end=" ")
    self.source = self.original_source.copy()
    self.contrast_multiplier = 1
    self.brightness_boost = 0
    return (self.observation, -1, False, self.info)

self.segments = list(get_lines_probabilistic(self.edges,
minimum_length=20))
self.segments_count = len(self.segments)
# 50 mrad ≈ 3°
self.unique_segment_angles = unique_angles(50e-3, self.segments)

print(f"bright {edges_brightness}, #seg {self.segments_count}", end=" =>
")

if (done := self.done()):
    self.last_winning_edges = self.edges.copy()
    self.last_winning_thresholds = self.thresholds.copy()

    return (
        self.observation,
        self.reward(edges_brightness),
        done,
        self.info,
    )

def render(self, window):
    import pygame

    window.fill((255, 255, 255))
    self._draw_image(self.original_source, window, (0, 0))
    self._draw_text("original", window, 0, self.image_dimensions[1] + 20)
    self._draw_image(self.source, window, (self.image_dimensions[0], 0))
    self._draw_text(f"original * {self.contrast_multiplier} +
{self.brightness_boost}\nblur {self.blur * self.step_blur_value}", window,
self.image_dimensions[0], self.image_dimensions[1] + 20)
    self._draw_image(self.edges, window, (self.image_dimensions[0]*2, 0))
    self._draw_text(
        f"""
        thresh lo {self.thresholds[0]} hi {self.thresholds[1]}
        bright {brightness_of(self.edges):.2f}
        segments count {self.segments_count}
        """, window, self.image_dimensions[0]*2, self.image_dimensions[1] +
20)
    self._draw_image(self.last_winning_edges, window,
(self.image_dimensions[0]*3, 0))
    self._draw_text(
        f"""
        tresh were lo {self.last_winning_thresholds[0]} hi
{self.last_winning_thresholds[1]}
        in {self.acceptable_brightness_range}
        in {self.acceptable_segments_count_range}
        """,
        window,
        self.image_dimensions[0]*3,
        self.image_dimensions[1] + 20,
    )

    self._draw_text(
        f"""
        {self.current_image_name}
        {self.ε*100:.1f}% eXploration {(1-self.ε)*100:.1f}% Exploitation
        """,
        window,
        int(self.image_dimensions[0]*1.5),
        self.image_dimensions[1] + 75,
    )

pygame.display.update()
```

```
def _draw_text(self, text, window, x, y, width=None):
    import pygame

    text = inspect.cleandoc(text)
    if width is not None:
        text = textwrap.fill(text, width=width)
    pygame.init()
    font = pygame.font.SysFont("monospace", 12)
    for i, line in enumerate(text.splitlines()):
        text_surface = font.render(line, True, (0, 0, 0))
        window.blit(text_surface, (x, y + i * 12))

def _draw_image(self, image, window, *at):
    import pygame

    if len(image.shape) < 2:
        return
    size = image.shape[1::-1]
    cv2_image = np.repeat(image.reshape(size[1], size[0], 1), 3, axis=2)
    surface = pygame.image.frombuffer(cv2_image.flatten(), size, "RGB")
    surface = surface.convert()
    window.blit(surface, at)

def close(self):
    if self.window is not None:
        import pygame

        pygame.display.quit()
        pygame.quit()
```

```
import random
from collections import deque
from pathlib import Path
from datetime import datetime
import numpy as np
from numpy import array
from tensorflow.keras.layers import (
    BatchNormalization,
    Conv2D,
    Conv3D,
    Dense,
    Dropout,
    Flatten,
    Input,
    MaxPooling2D,
)
from tensorflow.keras.models import Model
from tensorflow.keras.optimizers import Adam
from rich import print
from rl_environment import EdgeDetectionEnv
from utils import partition
```

rl_agent.py

Agent pour l'apprentissage par renforcement

```
REPLAY_MEMORY_SIZE = 1_000
MIN_REPLAY_MEMORY_SIZE = 333
```

```
class NeuralNetwork:
    # Creates a convolutional block given (filters) number of filters, (dropout)
    dropout rate,
    # (bn) a boolean variable indicating the use of BatchNormalization,
    # (pool) a boolean variable indicating the use of MaxPooling2D
    def conv_block(self, inp, filters=64, bn=True, pool=True, dropout=0.2):
        _ = Conv2D(filters=filters, kernel_size=3, activation="relu")(inp)
        if bn:
            _ = BatchNormalization()(_)
        if pool:
            _ = MaxPooling2D(pool_size=(2, 2))(_)
        if dropout > 0:
            _ = Dropout(0.2)(_)
        return _

    def __init__(self, conv_list, dense_list, input_shape, dense_shape):
        print(f"neural: init: conv: {conv_list}; dense: {dense_list}; in: {input_shape}; out: {dense_shape}")
        # Defines the input layer with shape = ENVIRONMENT_SHAPE
        input_layer = Input(shape=(input_shape, 1))
        print(input_shape, input_layer.shape)
        # Defines the first convolutional block:
        print(f"Constructing block #1")
        _ = self.conv_block(input_layer, filters=conv_list[0], bn=False, pool=False)
        # If number of convolutional layers is 2 or more, use a loop to create them.
        if len(conv_list) > 1:
            for i, c in enumerate(conv_list[1:]):
                print(f"Constructing block #{i + 2}")
                _ = self.conv_block(_, filters=c)
        # Flatten the output of the last convolutional layer.
        _ = Flatten()(_)

        # Creating the dense layers:
        for d in dense_list:
            _ = Dense(units=d, activation="relu")(_)
        # The output layer has 4 nodes (one node per action)
        output = Dense(units=dense_shape, activation="linear", name="output")(_)

        # Put it all together:
        self.model = Model(inputs=input_layer, outputs=[output])
        self.model.compile(
            optimizer=Adam(lr=0.001),
            loss={"output": "mse"},
            metrics={"output": "accuracy"},
        )
```

```
class EdgeDetectionAgent:
    ACTION_NAMES = ["high_threshold", "low_threshold", "contrast", "brightness", "blur"]
```

```
def __init__(
    self,
    name,
    env: EdgeDetectionEnv,
    conv_list,
    dense_list,
    memory_sample_size,
    discount_rate,
    update_target_model_every,
) → None:
    self.env = env
    self.conv_list = conv_list
    self.dense_list = dense_list
    self.memory_sample_size = memory_sample_size
    self.last_save = None
    self.discount_rate = discount_rate
    self.update_target_model_every = update_target_model_every
    self.name = f"{name}_conv:{'.'.join(map(str, conv_list))}_dense:{'.'.join(map(str, dense_list))}_mem:{memory_sample_size}_γ:{discount_rate}"

    print(env.observation_space_shape)

    self.model = NeuralNetwork(
        conv_list,
        dense_list,
        input_shape=env.observation_space_shape,
        dense_shape=env.action_space_shape,
    ).model
    self.target_model = NeuralNetwork(
        conv_list,
        dense_list,
        input_shape=env.observation_space_shape,
        dense_shape=env.action_space_shape,
    ).model
    self.target_model.set_weights(self.model.get_weights())
    self.replay_memory = deque(maxlen=REPLAY_MEMORY_SIZE)
    self.current_step_count = 0
    print(f"agent {self.name} initialized")

    def save_model(self, inside: Path):
        now = datetime.now()
        self.last_save = now
        timestamp = now.strftime("%Y-%m-%dT%H_%M_%S")
        self.model.save(inside / timestamp / "model.h5")
        self.target_model.save(inside / timestamp / "target_model.h5")

    def remember(self, transition):
        self.replay_memory.append(transition)

    def train(self, terminal_state, step):
        if len(self.replay_memory) < max(self.memory_sample_size, MIN_REPLAY_MEMORY_SIZE):
            return

        print("sample", end=" ")
        memory_sample = random.sample(self.replay_memory, self.memory_sample_size)
        current_states = array([end for _, _, end, _ in memory_sample])
        future_states = array([start for start, _, _, _ in memory_sample])
        print("predict", end=" ")
        current_q_values = self.model.predict(current_states.reshape(-1, *self.env.observation_space_shape))
        future_q_values = self.target_model.predict(future_states.reshape(-1, *self.env.observation_space_shape))
        training_states = []
        training_q_values = []

        print(f"apply memory", end=" ")
        for index, (current_state, action, reward, future_state, done) in enumerate(memory_sample):
            for action_name, action_idx in self.neural_indices_of(action).items():
                new_q = reward + (
                    self.discount_rate *
                    np.max(self.q_values_of_action(future_q_values[index], action_name))
                    if not done
                    else 0
                )
```

```
            try:
                current_q_values[index, action_idx] = new_q
            except IndexError as e:
                print(f"Tried indexing {index, action_idx} ({action_name} += {action[action_name]}) in {current_q_values.shape} Q-values")
                raise e

            training_states.append(current_state)
            training_q_values.append(current_q_values[index])

        print(f"fit", end=" ")
        self.model.fit(
            x=array(training_states).reshape(-1, *self.env.observation_space_shape),
            y=array(training_q_values),
            batch_size=self.memory_sample_size,
            verbose=0,
            shuffle=False,
            callbacks=[],
        )

        if terminal_state:
            self.current_step_count += 1

        print("set weights")
        if self.current_step_count % self.update_target_model_every == 0:
            self.target_model.set_weights(self.model.get_weights())

        def get_q_values(self, state):
            return self.model.predict(state.reshape(-1, *self.env.observation_space_shape))

        def what_do_you_want_to_do(self, state):
            q_values = self.get_q_values(state).flatten()
            keys = self.ACTION_NAMES
            sizes = [self.env.action_space_layout[k][0] for k in keys]
            offsets = [self.env.action_space_layout[k][1] for k in keys]
            return {
                keys[i]: np.argmax(q_values_for_key + offsets[i]
                    for i, q_values_for_key in enumerate(partition(q_values, sizes))
                )
            }

        def neural_indices_of(self, action: dict) → dict[str, int]:
            """
            Returns a map of action names to the index of their values in the neural network's output layer.
            """
            return {name: self.neural_index_of(name, nudge) for name, nudge in action.items()}

        def neural_index_of(self, name: str, nudge: int) → int:
            """
            Returns the index of the value of the action named 'name' in the neural network's output layer.
            """
            cursor = 0
            for action_name in self.ACTION_NAMES:
                size, offset = self.env.action_space_layout[action_name]
                if action_name == name:
                    return cursor + (nudge - offset)
                cursor += size

        def q_values_of_action(self, q_values, action_name: str) → list[float]:
            size, offset = self.env.action_space_layout[action_name]
            max_nudge = size + offset
            start = self.neural_index_of(action_name, 0)
            end = self.neural_index_of(action_name, max_nudge)
            return q_values[start : end + 1]
```


rl_training.py

Processus d'entraînement de l'agent

```
import random
from datetime import datetime, timedelta
import numpy as np
from typing import NamedTuple, Tuple, Union
import gym
from rl_environment import EdgeDetectionEnv
from rl_agent import EdgeDetectionAgent
from tqdm import trange
from pathlib import Path
import pygame
from rich import print, traceback

traceback.install()

env = EdgeDetectionEnv(
    render_mode=None,
    acceptable_brightness_range=(7, 15),
    acceptable_segments_count_range=(10, 25),
    dataset=Path("datasets/radiopaedia/cropped"),
    max_thresholds_increment=5,
    max_blur_value=50,
    step_blur_value=10,
    max_brightness_increment=3,
)

# WINDOW = pygame.display.set_mode((1000, 300))
# clock = pygame.time.Clock()

class Params(NamedTuple):
    memory_sample_size: int
    ε_fluctuations: int # 0 to disable ε fluctuation
    max_episodes_count_without_progress: int = 0 # where
    progress means an increment in reward. Use 0 to disable ECC
    ε_bounds: Tuple[Union[int, float], Union[int, float]] =
    (0.001, 1)

def run(env: EdgeDetectionEnv, agent: EdgeDetectionAgent,
params: Params):
    episode_reward = 0
    ε = 1
    # ε_values = [ε]
    # rewards_history = []
    # episodes_without_progress_count = 0
    ε_decay = params.ε_bounds[1] - (
        params.ε_bounds[1] / int(env.dataset_size /
(params.ε_fluctuations or 0.8 * env.dataset_size))
    )
```

```
episode = 0
while not env.saw_everything:
    reward = 0
    step = 1
    action = 0

    current_state = env.reset()

    while not env.done():
        print(f"{datetime.now():%H:%M:%S}", end=" ")
        print("choose", end=" ")
        if random.random() > ε:
            print(f"[bold][magenta]E[/bold][[/magenta]
{ε*100:.1f}%]", end=" ")
            print("network", end=" ")
            action =
agent.what_do_you_want_to_do(current_state)
        else:
            print(f"[bold][cyan]X[/bold][[/cyan]
{ε*100:.1f}%]", end=" ")
            print("random", end=" ")
            action = env.action_space.sample()

        print("step", end=" ")
        new_state, reward, done, info =
env.step(action, ε)
        print(f"rewarded with {reward}", end=" ")
        episode_reward += reward

        print("remember", end=" ")
        agent.remember((current_state, action, reward,
new_state, done))
        print("train", end=" ")
        agent.train(done, step)

        current_state = new_state
        step += 1

        if agent.last_save is None or
abs(agent.last_save - datetime.now()) >
timedelta(minutes=15):
            agent.save_model(Path(__file__).parent /
"rl_models" / agent.name)

        # print("render", end=" ")
        # env.render(WINDOW)
        print("")

    print("== episode done! ==")
```

```
if ε > params.ε_bounds[0]:
    print(f"decaying {ε = }")
    ε = max(ε * ε_decay, params.ε_bounds[0])

if params.ε_fluctuations and episode %
int(env.dataset_size / params.ε_fluctuations) == 0:
    print(f"flucuating {ε = }")
    ε = params.ε_bounds[1]

env.save_settings(agent.name, Path(__file__).parent
/ "rl_reports")

print("=====")
episode += 1

# if episode_reward == rewards_history[-1]:
#     episodes_without_progress_count += 1

# rewards_history.append(episode_reward)

# if episodes_without_progress_count >
params.max_episodes_count_without_progress:
#     ε = ε_values[-1]

if __name__ == "__main__":
    params = Params(memory_sample_size=128,
ε_fluctuations=2)
    agent = EdgeDetectionAgent(
        "perseverance",
        env,
        conv_list=[32],
        dense_list=[32, 32],
        discount_rate=0.99,
        memory_sample_size=params.memory_sample_size,
        update_target_model_every=5,
    )

    run(env, agent, params)
```