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Visualisation and Simulation of Pedestrians at Train Stations

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Abstract **-** Space utilization by humans is an important aspect in building design, especially for buildings with a substantial flow of pedestrians like train stations. We aim at a simulation of pedestrian flows as a visual feedback in the planning phase of buildings. The simulation has to provide feedback for the layout and dimensions of floor space. This includes the general organization of space as well as capacities or congested and high collision areas. After observing pedestrians at the Westbahnhof, a major train station in the capital city of Austria, movements of pedestrians within a train station have been simulated and visualized. The real-time simulation is based on a multi-agent approach, where the individual agents are controlled by a behavioural model which employs three levels: strategic, tactical and operational. In our behavioural model, a strategy specifies the reason a person visits a place (e.g. to depart) and consists of several activities on the tactical level. While the strategy is constant for an agent during its lifetime, activities (e.g. to buy food, to use a toilet, to buy a newspaper) and associated activity areas are chosen and prioritized dynamically by each agent. This results in a coarse route through the facility. The operational level consists of path planning and obstacle avoidance. The simulation was implemented with the Unity framework and exemplified via a 3D model of the train station.

Keywords**:** Pedestrian simulation, train station, building design support, behavioural model

1. Introduction

When planning a building with a substantial flow of pedestrians like a train station, it is indispensable to consider the space utilisation of people within such a building. So far, building designers get little support in the planning phase with regard to interactive real-time feedback on the chosen layout and dimensions.

Usually, computer-aided simulations of pedestrian behaviour are not working in real-time, or they are poorly integrated within the design process. An interactive real-time simulation of pedestrian flows as a visual feedback in the planning phase of buildings would be needed. This simulation should enable designers to evaluate whether a planned building fulfils the spatial requirements of the people who frequent the building. Useful feedback for the planning phase should visualize low-traffic and high-traffic areas, traffic density, and customer frequencies and indicate frequently used paths to illustrate the efficiency of the planned layout and dimensions.

Therefore, we aim at a simulation and visualisation of pedestrian behaviour as design support in order to provide a means to validate planned dimensions. We explicitly do not address evacuation situations. We also do not aim at simulating pedestrian flow for longer time periods (based on a realistic schedule) within the scope of this work, but provide a proof-of-concept simulation which visualises space utilisation for a specific situation and limited duration. Our goal is to mainly provide visual feedback for planners (architects), so the visualisation concept is an important aspect. Also, we put a focus on the behaviour of people. This results in a more accurate modelling of the behaviour of pedestrians, rather than a high number of pedestrians.

This work aims at answering the following research questions: How can the planning of train stations be supported by pedestrian simulation in order to better understand the spatial requirements?

How can crowd simulation with its aspect of human interaction within time and space support the planning phase with little effort?

2. Planning Space Requirements of Train Stations

The idea of personal space around a person ("comfort zone") was introduced by [1]. The size of this space varies with culture and crowd density. The spatial requirements of people within a building are an important aspect of consideration for building planners [2]. In addition to the three dimensions of a building, time and human interaction are two further important dimensions. With static building models, these further dimensions are hard to explore. In order to be able to evaluate the spatial qualities of a building, the architect has to imagine the interaction of people in and with the building. This is a difficult task, even for experienced architects [3]. To ameliorate the design process, we suggest the use of simulation as a feedback for the space utilisation of pedestrians moving within the building model.

There are standard values for diverse buildings concerning the spatial requirements of people. The standard reference for building and site planning [2] thoroughly discusses spatial requirements grouped by project types and offers empirical values for a variety of measurements. With regard to train stations, it includes guidelines for basic planning, platforms and tracks, conveyance and seating, required facilities, persons, and barrier-free movement. High-level functional requirements concerning train stations are discussed in [4]. These include topics like integration with the city, traffic centre, arrangement, and required facilities.

3. Crowd Modelling

Crowd behaviour has been studied by many, e.g. [5, 6, 7, 8, 9, 10] which serves as basis for crowd modelling. Crowd behaviour has been modelled with several approaches [11, 12, 13], e.g. with behavioural models, force-field models, or data-driven models. Behavioural models model each single agent's behaviour with respect to other agents or the environment. They use diverse techniques to control their individual agents, e.g. rules or reasoning. The actual knowledge about other agents' motion data is varying in the different models. In force-field models, the crowd behaviour is controlled by attractive and repulsive forces which are calculated for each cell of the grid that represents the simulation world [7]. In data-driven models, statistical data is used to control the behaviour of the simulated crowd. Usually, observation of people is the means for gathering the required data.

In behavioural models, individual modelling of the single agents is better than in the other models. With a focus on the crowd as a whole, force-field models provide easier control. In data-driven models, a higher realism for specific aspects of the crowd can be achieved. Hybrid models take advantage of the different approaches at the cost of increased complexity. They are usually combined in a hierarchical way.

For a real-time simulation, the complexity of the models has to be kept on a moderate level. There are techniques to enhance performance, though, e.g. [11, 14].

The behavioural model in our work is derived from the hierarchical approach devised by [16] which distinguishes the three levels: strategic, tactical, and operational. A checklist for features of pedestrian simulation is provided by [15].

4. Case Study

In order to gather reasonable data for the simulation, a major train station was chosen for a case study, the Westbahnhof (see Figure 1) in Vienna. At the time of observation, it handled the west-bound traffic (commute, long-distance, and local) and connected to other city infrastructure like underground, trams, and buses, as well as car and bicycle parking, shopping mall, food court, hotels and offices.

For the non-intrusive observation on site, a person took notes of pedestrian activities in different areas of the station for a short period of time in order to compile a list of activities with associated parameters (Table 1). To see typical trajectories, some pedestrians were followed through the train station. Also for finding activity patterns, people had to be observed non-stationary.

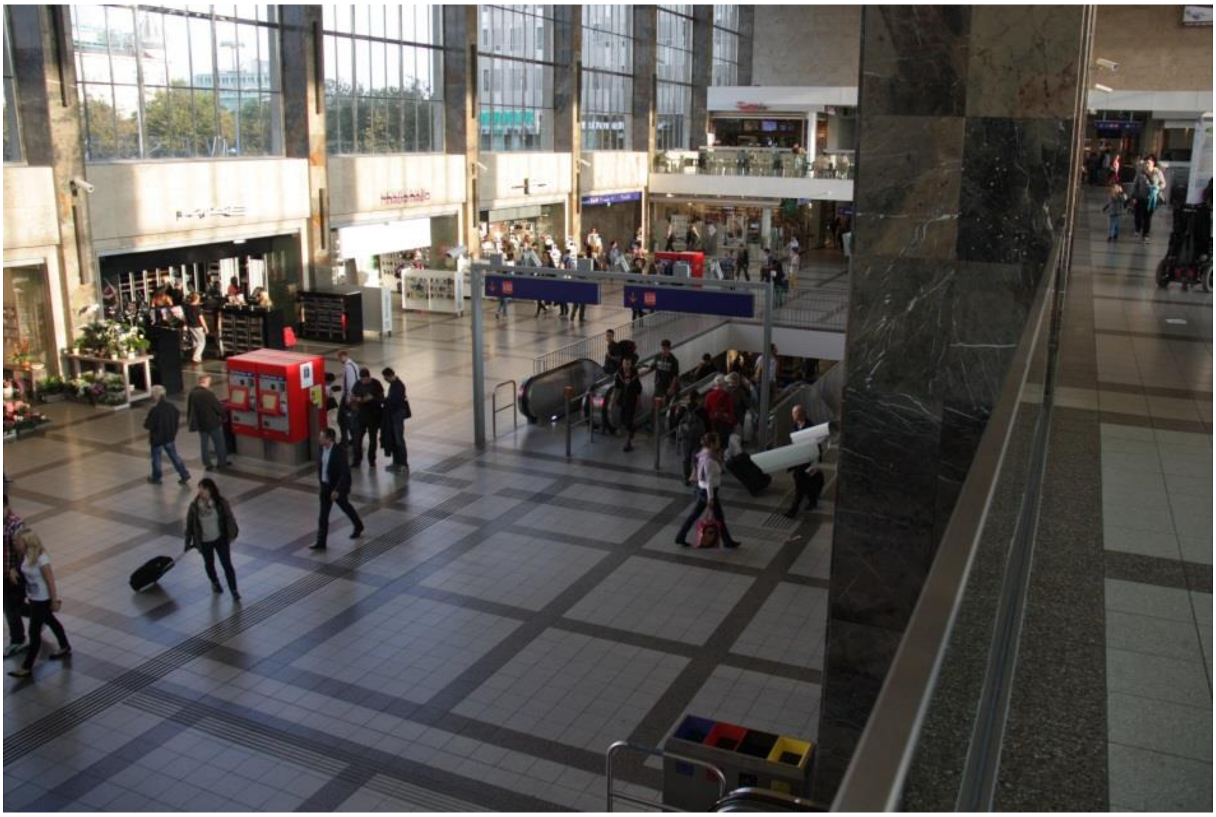


Fig. 1: Observations at the train station Westbahnhof.

Table 1: Deriving activities and strategies from observations.

Observation				
Motion type	walk	walk	stand	stand
Activity	go to	go to	buy ticket	take picture
Object	trolley	small bag	-	-
Strategy	depart	arrive	depart	unknown

In order to estimate numbers for passenger flows, pedestrians have been counted in specific areas in the concourse. Figure 2 illustrates pedestrian streams on the ground floor coming from the left part of the building (shopping mall) into the concourse.

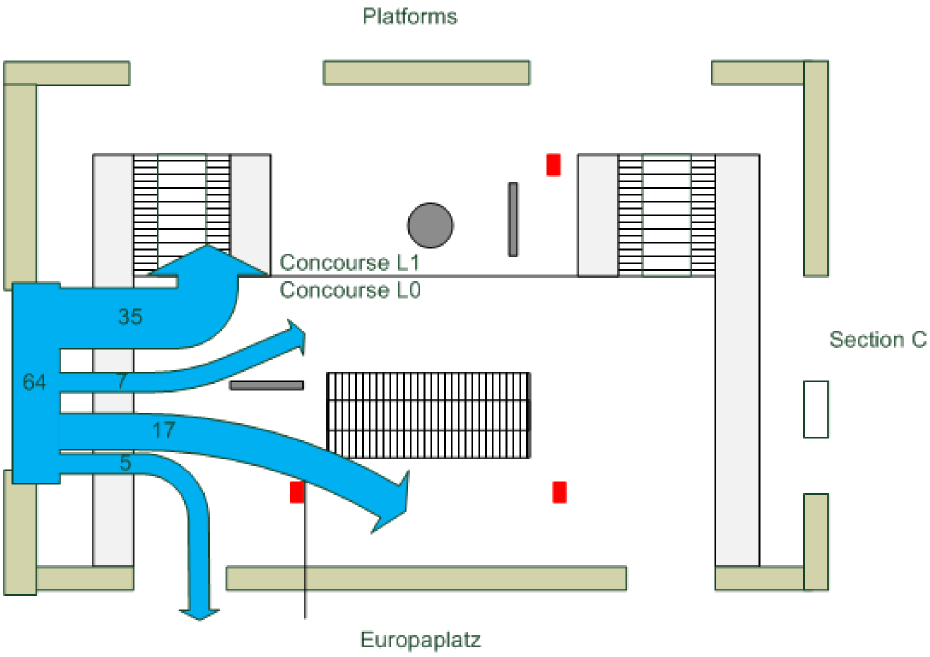


Fig. 2: Pedestrian flows from the left into the train station. Some pedestrians move to the outside (Europaplatz), some move upstairs to the upper floor of the concourse, while others move about in the main hall (lower floor of the concourse).

5. Results

5.1. Behavioural Model

In order to simulate pedestrian behaviour in both a simple and realistic way, a utility-based behavioural model has been devised. Pedestrians are represented by agents whose behaviour is modelled on three levels according to [16]:

The **strategic** level indicates the reason an agent visits the facility in the first place. An agent's strategy determines probabilities for each possible activity, i.e. it can be described as a probability graph (see Figure 3). Thus, agent-behaviour is non-deterministic across simulation runs. Probabilities have been derived from quantitative on-site observations (see section 4).

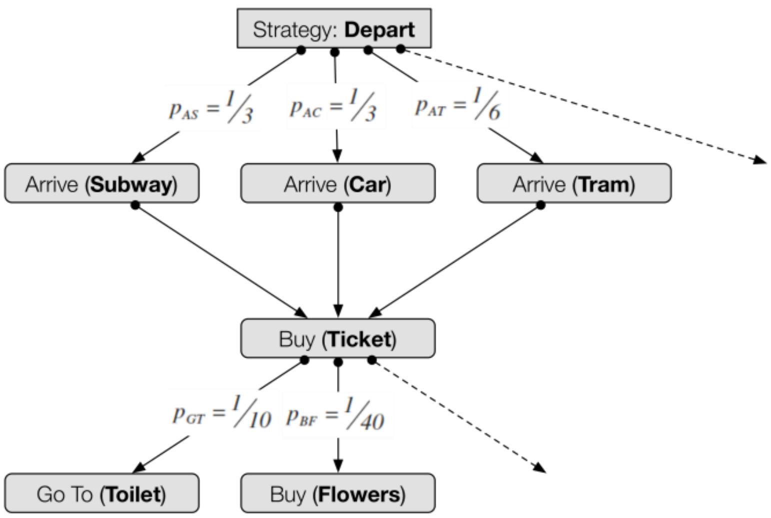


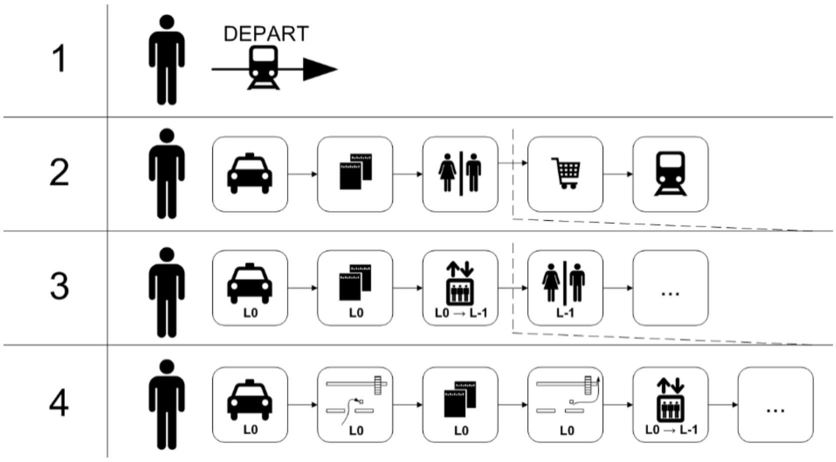
Fig. 3: Exemplary activity graph for the strategy depart.

On the **tactical** level, each agent actually chooses and prioritizes a set of activities from the strategy. Each such ordered activity set corresponds to one of many possible activity patterns that fit the chosen strategy. Activities are parametrized, e.g. by motion type (e.g. stand, walk), and social form. Further parameters are: associated object, preferred walking speed, gender, age, appearance, activity areas.

On the **operational** level, each agent plans and follows a path towards the next activity, respectively. In order to make activities available to the agents that are not positioned on the same floor, path planning operates on two levels: High level path planning (“master navigation”) allows the agent to reach other floors of the building, while low-level path planning allows the agent to reach any activity on the same floor.

Table 2 shows an example for the strategy “depart” on all three (four) levels. Level 1 indicates the chosen strategy. This is broken down into a list of selected activities on level 2. The actual activities for each agent are chosen according to the activity graph, i.e. according to observed probabilities. In Table 2, the following choices are depicted: arrive in taxi, buy ticket, go to toilet, shop, and depart. In level 3, these activities are operationalized according to the associated activity areas, i.e. coarse path finding by floor assignment (L0, L1). At level 4, local path finding is done.

Table 2: Exemplary agent behaviour on the (1) strategic, (2) tactical, and (3, 4) operational level.



The model includes plausible agent creation patterns (determined by arrival via different means of transport in the real world), strategy selection, and “realistic” motion (by following the utility-based approach on the tactical level and using collision avoidance on the operational level). It also employs queueing and waiting according to the semantics of an activity. Furthermore, it incorporates varied speeds for agents. Further details can be found in [17].

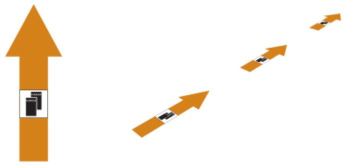
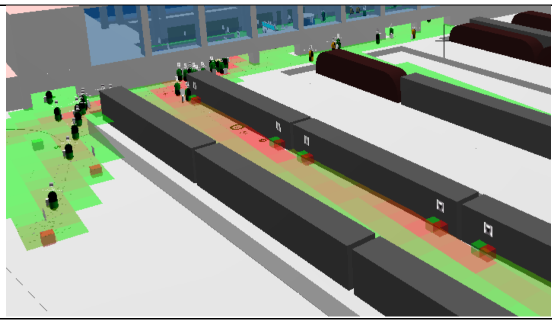
5.2. Visualization concept

This section describes a visualization concept for the behavioural model presented in section 5.1 as an information system that visualizes the spatial occurring parameters when applied to a geometric model. The main goal of the visualization is to provide a rapid prototyping tool for planning by using real-time simulation. A long term goal (future work) is a tight integration into planning software, so that the design (geometry and dimensions) are more easily changeable. A similar visualisation strategy for occupancy behaviour is presented in [18].

The information system displays information about strategy, next activity, direction, and velocity of each agent as well as accumulated density information at all times. Because an intuitive third person and first person view should facilitate conceiving of proportions and space utilization, both 3D and 2D visualizations are provided.

In order to minimize distraction, the information system presents a very abstract representation of geometry leaving out details and using only little texturing. Agents are represented by simple capsules. Actual spatial parameters are visualized as depicted in Table 3.

Table 3: Visualization of certain simulation parameters with screenshots from the implemented prototype.

Parameter	Visualization	Prototype Implementation
Space occupied by person	Capsule	
Strategy	Colour encodes strategy	
Trajectory	Direction and distance of “footprint” arrows (colour coded)	
Current / next activity	Colour coded capsule with activity icon above head and its footprints, text above head	
Density (accumulated)	Heatmap	

5.3. Proof-of-concept Prototype

In order to provide a proof-of-concept, essential parts of the model and visualization have been implemented in a prototype (see Figure 4) which features the train station geometry, an implementation of the model described in section 5.1, and an information system following the visualization concept described in section 5.2.

Outer dimensions of the train station geometry were derived from publicly available information from the city’s GIS department. As floor plans were not easily available, inner layout and dimensions where recreated and estimated from own photo material taken inside the station. The 3D models were created in SketchUp, and then transferred into Unity by converting to the open Collada (DAE) format.

Inside the Unity project, the visualization and all three levels of pedestrian behaviour have been implemented: Low-level (mesh) path planning and collision avoidance are provided by Unity, high-level (inter-mesh) path planning, activity management and strategies have been implemented in new components. In the current version 5, Unity provides “off-mesh links” which renders the effort for high-level path planning redundant. However, this feature was not available at the time the prototype was implemented.

Because transport facilities inside the building (lifts, escalators, stairs) are not trivial to simulate correctly, they have been abstracted using agent sinks and sources, which basically teleport agents from one floor to another. Sinks and sources are visualized using small, semi-transparent cubes.

The requirements have been reduced for performance and scoping reasons: Only one arriving train is fully simulated, while departing and shopping agents are partly simulated.

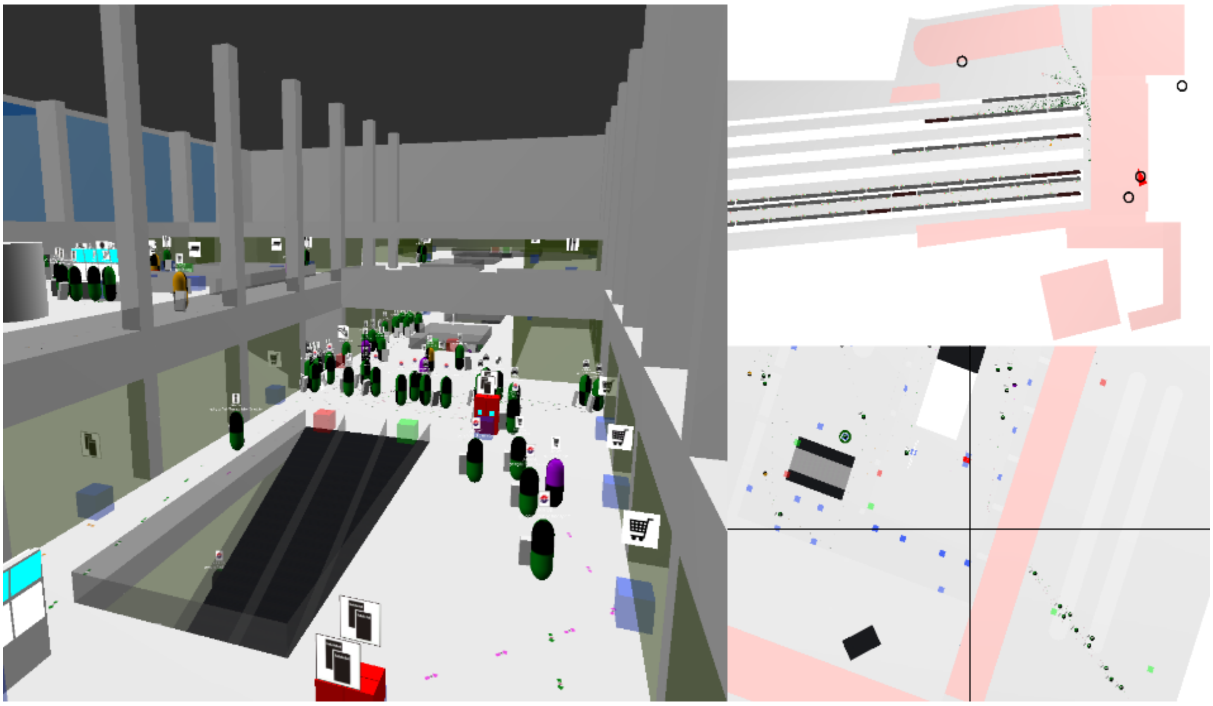


Fig. 4: Visualization of certain simulation parameters with screenshots from the implemented prototype. The left part displays a perspective view of the concourse with agents leaving foot trails and indicating their next goal. The upper right part displays a north-oriented overview of the train station with the observer's position and direction indicated by a red arrow. The lower right part shows an orthogonal, direction-aligned view onto the environment around the observer with crosshairs indicating the observer's position.

6. Discussion

Current planning processes mainly use static mock-ups to visualize planned buildings. Only very specific sub-problems like evacuation or usability of single elements are investigated using software simulation or full-scale prototypes. So far, there has been little financial interest in accurate simulation of pedestrian behaviour, even though a positive impact on building usability can be expected. This work has transferred observations made in a major transportation facility into a behavioural model and provides a prototype implementation of this model that visualizes space utilization over time. The implementation offers interactive functionality, which includes looking into agents' most common strategies and their most typical combinations of activities.

In contrast to static plans and mock-ups, real-time simulations can help identify problem areas. Supplied with an accurate behavioural model and arrival patterns, the software visualizes utilization from different perspectives in real-time. It provides valuable input for planning on two levels:

- The macro level allows representation of crowd behaviour over time by representing agent density / space utilization.
- The micro level allows representation of a single person's behaviour by representing an agent's strategy, activities and trajectory.

Even though the behavioural model is based on real-world observations, a means to validate the simulated behaviour is necessary in order to prove the realism of the simulation.

A further adaptation could be a dynamic time planning per agent for a more realistic motion and activity planning. Currently, this is implicitly modelled via probabilities.

The long-term goal is to enhance the building design workflow by facilitating the interactive, incremental improvement of a semantic (eventually procedural) 3D model using simulation feedback.

This work provides fast feedback on space utilization and spatial parameters. Steps to reach the long-term goal would be: facilitating geometry import (including semantics); editing geometry in real-time; interactively changing the parameters of the procedural architectural model according to the simulation feedback. At the same time, more statistical data like capacity, utilization, and dimensions could be visualized.

People use information to navigate a facility that can be seen as a "mental map". In the real world, the amount of this map information can range from very low for people who visit for the first time to very high for people who are already familiar with the facility. Well-designed buildings make it easy for people to build a mental map. The current prototype implementation gives a complete mental map to each agent. If the incompleteness of mental maps is taken into account, the simulated behaviour can be quite different and provide valuable feedback on the building design.

The current prototype implementation supports the simulation of 1000 agents in real-time. Transportation buildings like airports and train stations are typically used by several thousand people concurrently. While an optimized, scalable solution was outside the scope of this work, it would be feasible utilizing GPU-based algorithms and multithreading or multiprocessing.

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