

midterm progress report

- **Group Name:** Mr. Li and Mr. Pan's Group
- **Project Process Name:** Fire Spread Simulation
- **Class Project Title:** Wildfire Spread Forecasting in Wildland-Urban Interface (WUI) Zones
- **Suggested Executer Name:** Yizhou Li, Zhiqing Pan

Introduction

Fire has been a long-existent phenomenon on Earth and an essential part of different ecosystems (Running 2006; Belcher 2013). With the rise of human civilization and the expansion of living space, humans are gradually occupying the wildlands to create more urban areas. Meanwhile, our human activities have caused more and more wildfires and increased the frequency of extreme wildfires. Once a wildfire occurs, it primarily affects the residents who live in the emerging wildland-urban interface (WUI) (Theobald and Romme 2007; Gill and Stephens 2009).

Hong Kong is a highly populated modern city with over 4,000 skyscrapers, but it also has ~70% of its land covered by woodland, shrubland, and wetland (Lee et al. 2017). Therefore, it is a typical WUI that is constantly threatened by wildfires. According to the data from Hong Kong Fire Services Department ('Hong Kong Fire Services Department - Access to Information' 2021), about 1,000 wildfires (or hill fires) are reported annually. Over 80% of wildfires witness a burning area of less than 1,000 m² and a burning time of 24 h because of significant firefighting efforts. Still, some wildfires spread to nearby high-population urban areas that cause significant safety issues and air pollution.

Wildfire behavior is a complex and dynamic phenomenon influenced by various factors, including the characteristics of the fuel, topography, weather conditions, and local landscape. As such, fire spread is not always linear or steady-state, and predicting its course can be challenging. In particular, sudden changes in weather conditions or the ignition of new fires can cause rapid shifts in the pattern of wildfire spread, potentially breaching established firebreaks and endangering previously safe areas. Therefore, accurate forecasting of real-time or short-term trends in fire spread is essential for effective wildfire management, particularly in wildland-urban interface (WUI) zones. Real-time fire spread forecasts can aid fire services in allocating resources, planning evacuations, and implementing other emergency response measures by predicting a fire's expected trajectory and intensity. These predictions can also assist residents in making informed decisions about their safety and help to prevent loss of life and property damage.

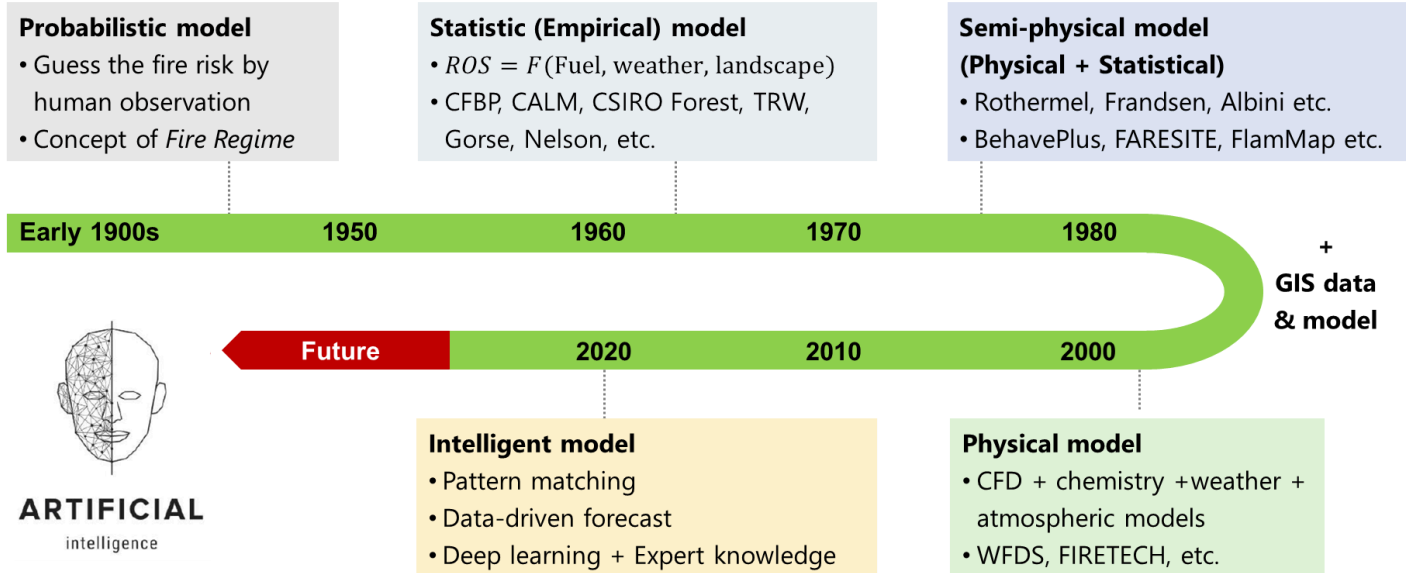
Literature Review

Researchers have attempted to simulate wildfires and forecast their spread behaviors since the 1950s or even earlier. In the early days, most models were simple and probabilistic, based on limited human observation and experience. These models mainly assessed the wildfire risk but could not predict wildfire spread (Skinner and Chang 1996). Later in the 1970s, more understanding of wildfire dynamics was introduced to the mathematical model. Notably, Rothermel proposed a widely used semi-physical formula that considers different factors of fire, fuel, landscape, and weather to calculate the wildfire spread (Rothermel 1972). In the 1990s, several software tools had been developed to program these semi-physical models and environment parameters to predict 2-D wildland fire spread. For example, FARSITE (later becoming a part of FlamMap) coded Rothermel's equation to simulate and visualize wildfire propagation (Finney 1998). The running of FARSITE needs input from the Geography Information System (GIS), but the data from wildland fuel, weather, and landscape are often challenging to acquire accurately.

(a) Global wildfires



(b) Evolution of wildfire modelling



Since the 2000s, several numerical software was developed for physics-based fire modellings, such as HIGRAD/FIRETEC and Wildland Fire Dynamics Simulator (WFDS) (Hoffman et al. 2016). These tools are based on computational fluid dynamics (CFD) that can solve the atmospheric flow field and ground boundary flow near the fire (Anderson and Wendt 1995). These tools make wildfire simulation exquisite but consume considerable time and require high computation costs. Overall, the wildfire modelling method is evolving from statistics-based models to physical-based models. Nevertheless, all these computational tools are too slow to give real-time forecasts of wildland fire development. For example, forecasting the wildfire front in a few minutes often takes CFD-based software to run hours, so these kinds of wildfire simulations neither help guide the wildfire emergency response nor plan the prescribed burning.

To overcome the above issues, more recently, new artificial intelligence (AI) models have been proposed for fire forecast (Wang et al. 2022; Wu et al. 2022; Zhang et al. 2022), including wildfire forecast, which is an emerging research topic (Radke et al. 2019; Allaire et al. 2022; Jiang et al. 2022). The mathematic-based computation can be switched into a data-driven matchup in the database, where AI models calculate the mathematical relations among different parameters within seconds. Many researchers optimized the traditional models with AI models to increase the accuracy of forecasts (Radke et al. 2019; Zhou et al. 2020). Also, deep learning was widely used to explain and predict the wildfire spread rate (Zhai et al. 2020; Storey et al. 2021; Li, Lin, et al. 2022). Deep learning models were also adopted to map and forecast the wildfire risk possibility (Jaafari et al. 2019; Le et al. 2020; Allaire et al. 2022). Meanwhile, the AI-based models primarily decreased the computation time and made the long-term forecast possible in simulating wildfires (Hodges and Lattimer 2019; Sung et al. 2021; Li, Zhang, et al. 2022).

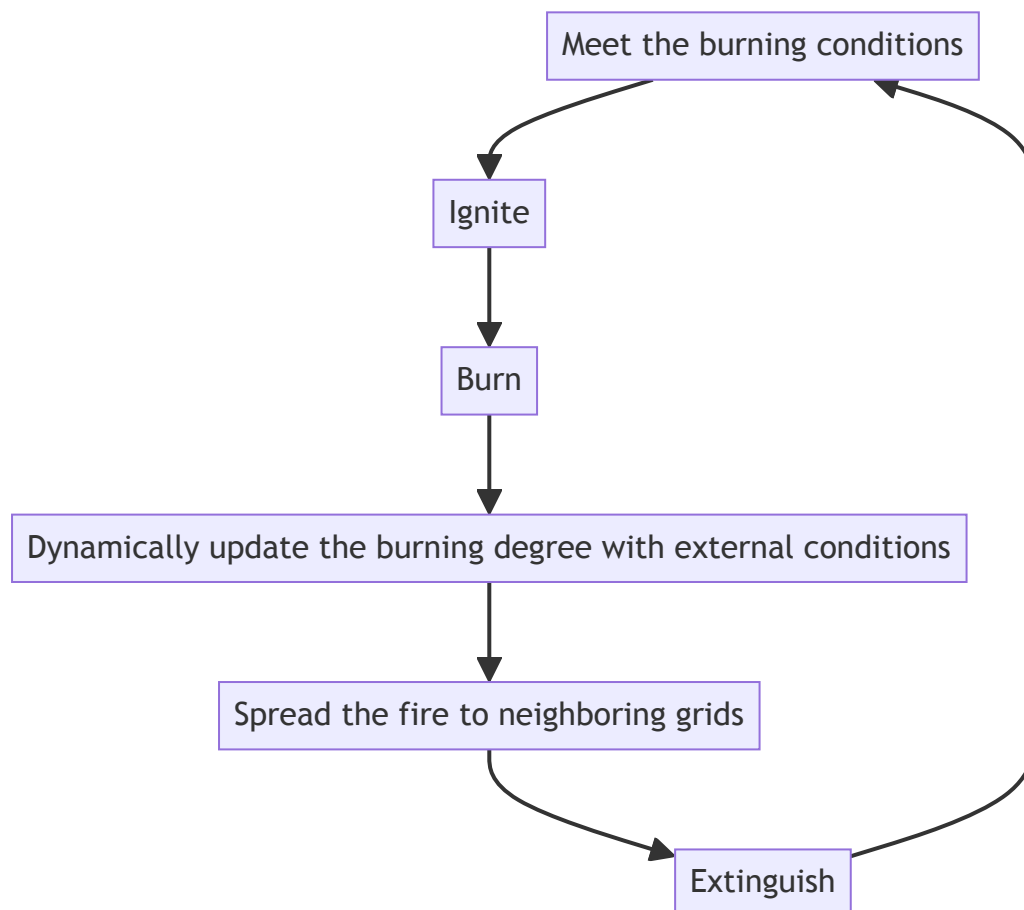
Equipment and Steps Description

我们可以使用网格划分的方式来模拟火灾蔓延，每一个网格代表一个小区域，存放0~1之间的数值，表示这个区域的燃烧程度。0表示没有燃烧（或自灭），1表示最大燃烧。现在，对于某一单独的网格，从满足着火条件而着火到燃烧完全而熄灭，我们可以用一个简单的循环来模拟。

满足燃烧条件 -> 着火 -> 燃烧 -> 随着外界条件动态更新燃烧程度 -> 向邻近网格传播火势 -> 熄灭

在每一个时间步，我们可以根据风向、风速、地形、植被等因素的影响计算出火焰的蔓延方向和速度，然后更新每一个网格的燃烧程度。这样，我们就可以模拟出火灾的蔓延过程。对于每一个网格的燃烧时间，我们会使用蒙特卡洛模拟的方法来模拟。我们可以根据历史数据，计算出植被的燃烧时间的概率分布，然后根据这个概率分布来模拟每一个网格的燃烧时间。对于火势传播条件，我们会综合考虑风向、风速、地形、植被等因素。我们可以根据这些因素来计算出每一个网格的火势传播概率，然后根据这个概率来控制火势的传播。

We can use the grid division method to simulate the spread of the fire, where each grid represents a small area and stores a value between 0 and 1, indicating the degree of burning in that area. 0 indicates no burning (or self-extinguishing), and 1 indicates maximum burning. Now, for a single grid, from meeting the conditions for ignition to complete burning and extinguishing, we can simulate it with a simple loop.



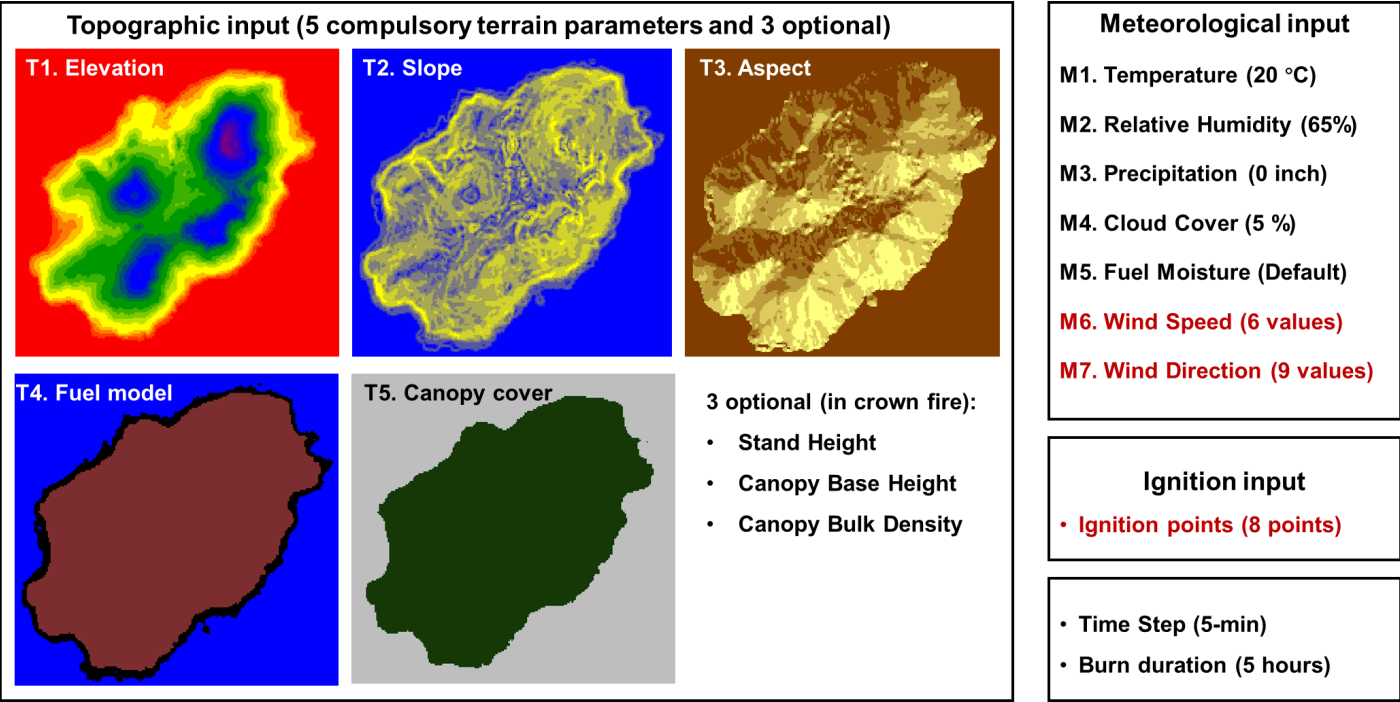
At each time step, we can calculate the direction and speed of the flame spread based on factors such as wind direction, wind speed, terrain, and vegetation, and then update the burning degree of each grid. In this way, we can simulate the spread of the fire. For the burning time of each grid, we will use the Monte Carlo simulation method to simulate it. We can calculate the probability distribution of the burning time of the vegetation based on historical data and then simulate the burning time of each grid based on this probability distribution. For the fire spread conditions, we will consider factors such as wind direction, wind speed, terrain, and vegetation. We can calculate the probability of fire spread for each grid based on these factors and then control the spread of the fire based on this probability.

Factors that Affect Productivity

- 1. Fuel Type and Moisture Content:** The type of fuel and its moisture content significantly affect the spread of wildfires. Dry fuels burn more easily and quickly than wet fuels. The moisture content of the fuel can be influenced by weather conditions such as rainfall and humidity.
- 2. Topography:** The slope and aspect of the terrain can affect the spread of wildfires. Steep slopes can cause fires to spread more rapidly, while flat terrain may slow down the fire's progress. The aspect of the terrain can also influence the direction in which the fire spreads.
- 3. Weather Conditions:** Wind speed and direction, temperature, and humidity can all impact the spread of wildfires. Strong winds can cause fires to spread more quickly, while high temperatures and low humidity can increase the likelihood of fires starting and spreading.
- 4. Vegetation Density:** The density of vegetation in an area can affect the spread of wildfires. Dense vegetation can provide more fuel for the fire to burn, while sparse vegetation may slow down the fire's progress.
- 5. Firefighting Efforts:** The effectiveness of firefighting efforts can also impact the spread of wildfires. Prompt and well-coordinated firefighting efforts can help contain fires and prevent them from spreading further.

Data Collection Procedure of the Selected Project

- 1. 地形数据:** 从香港政府的开源数据网站直接下载研究区域的地形数据, 随后使用ArcGIS 10.2软件对这些数据进行后处理, 得到精度为5米的地形数据。地形数据包括高程、坡度和坡向等信息, 这些信息将用于模拟火灾蔓延过程中的地形条件。
- 2. 气象数据:** 我们将使用香港气象局的气象数据, 包括风速、风向、温度和湿度等信息。这些数据将用于模拟火灾蔓延过程中的气象条件。
- 3. 燃料数据:** 我们将使用香港政府的植被数据来确定研究区域的植被类型和密度。这些数据将用于定制燃料模型, 以便更准确地模拟火灾蔓延过程。
- 4. 火灾历史数据:** 我们将使用香港消防处的火灾历史数据来确定岛屿上的火灾发生频率和规模。这些数据将用于评估火灾风险和制定应急响应计划。



2. **Meteorological Data:** We will use meteorological data from the Hong Kong Observatory, including wind speed, wind direction, temperature, and humidity information. This data will be used to simulate the meteorological conditions during the wildfire spread process.
3. **Fuel Data:** We will use vegetation data from the Hong Kong government to determine the vegetation types and densities in the study area. This data will be used to customize the fuel model to more accurately simulate the wildfire spread process.
4. **Fire History Data:** We will use fire history data from the Hong Kong Fire Services Department to determine the frequency and scale of fires on the island. This data will be used to assess fire risk and develop emergency response plans.

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