Image analysis

0. Introduction

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Motivation

Motivation

There is a growing interest among applied economists in using machine learning for predictive applications

- Accurate forecasting of economic and time-series variables (e.g. Moritz and Zimmermann 2016)
- Non-parametric tools for estimation (Belloni et al. 2012) and inference (Athey and Imbens 2016)
- Collection of original data for economic analysis (see Mullainathan and Spiess 2017 for a review)

Motivation

Important questions remain unanswered because the necessary data is encoded into high-dimensional structures

- Satellites have been taking high-resolution images of the earth for decades (Donaldson and Storeygard 2016)
- Increasing availability of digitised historical documents (i.e. OCR) and maps (Combes et al. 2021)
- Applications in spatial and development economics (e.g. street-view, aerial images) among others

Motivation

Transform high-dimensional structures into simpler representations for economic analysis. For instance

- Jean et al. (2016) or Mueller et al. (2021) convert satellite images into measures of development or destruction
- Naik et al. (2017) transform street-view images into measures neighbourhood improvements
- Gorin et al. (2025) extract building information form historical maps to study urban development

Motivation

Traditional econometric methods are not designed for these problems and either fail or perform poorly

- The data is high-dimensional and may not be structured as a two-dimensional array (e.g. pixels, characters)
- The data-generating process is unknown and no functional form is suggested by theory (Natekin and Knoll 2013)
- They focus on interpretability, unbiasedness and within sample performance (Kleinberg et al. 2015)

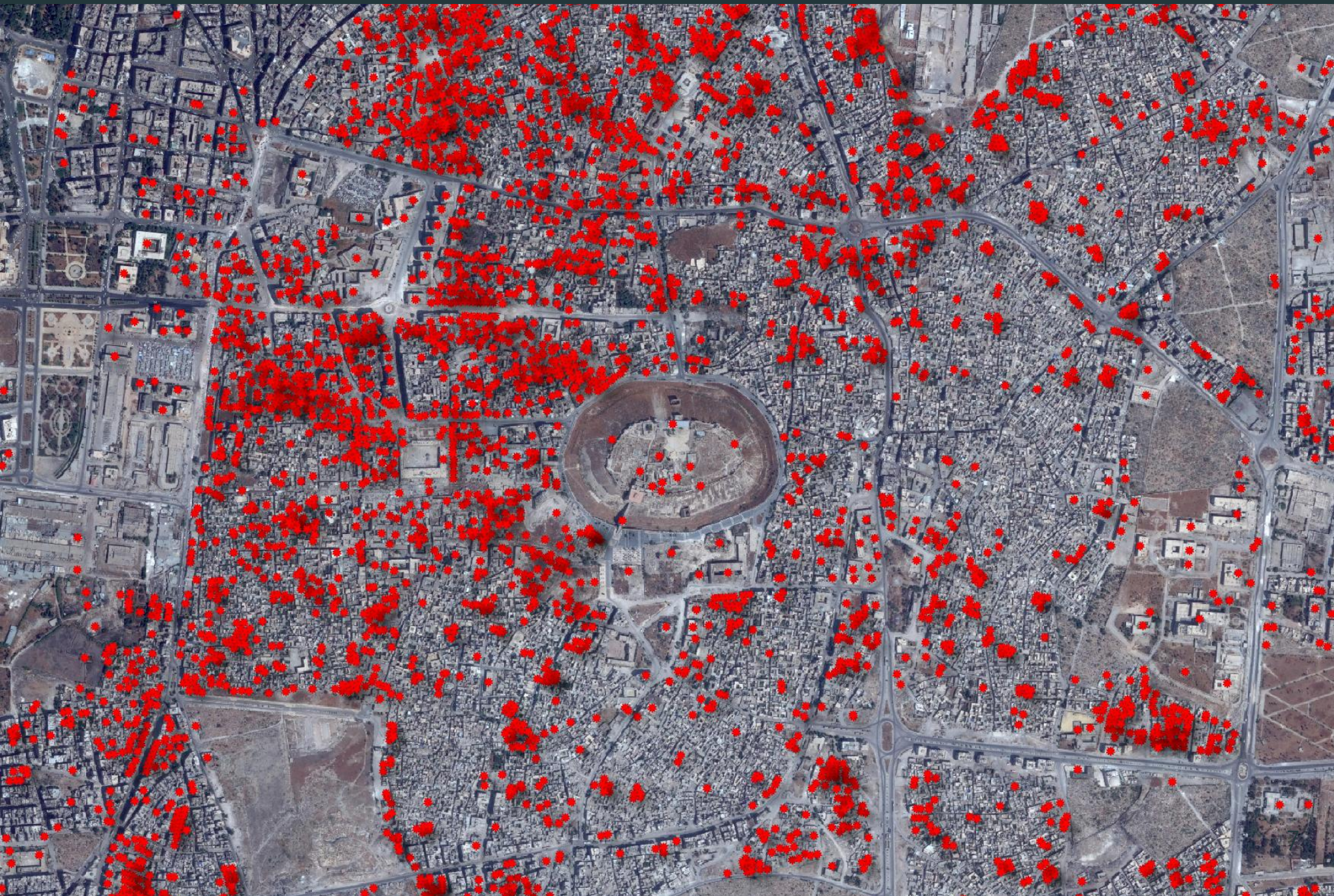
Motivation

Supervised leaning methods can be seen as building an empirical model from the sample data using many parameters

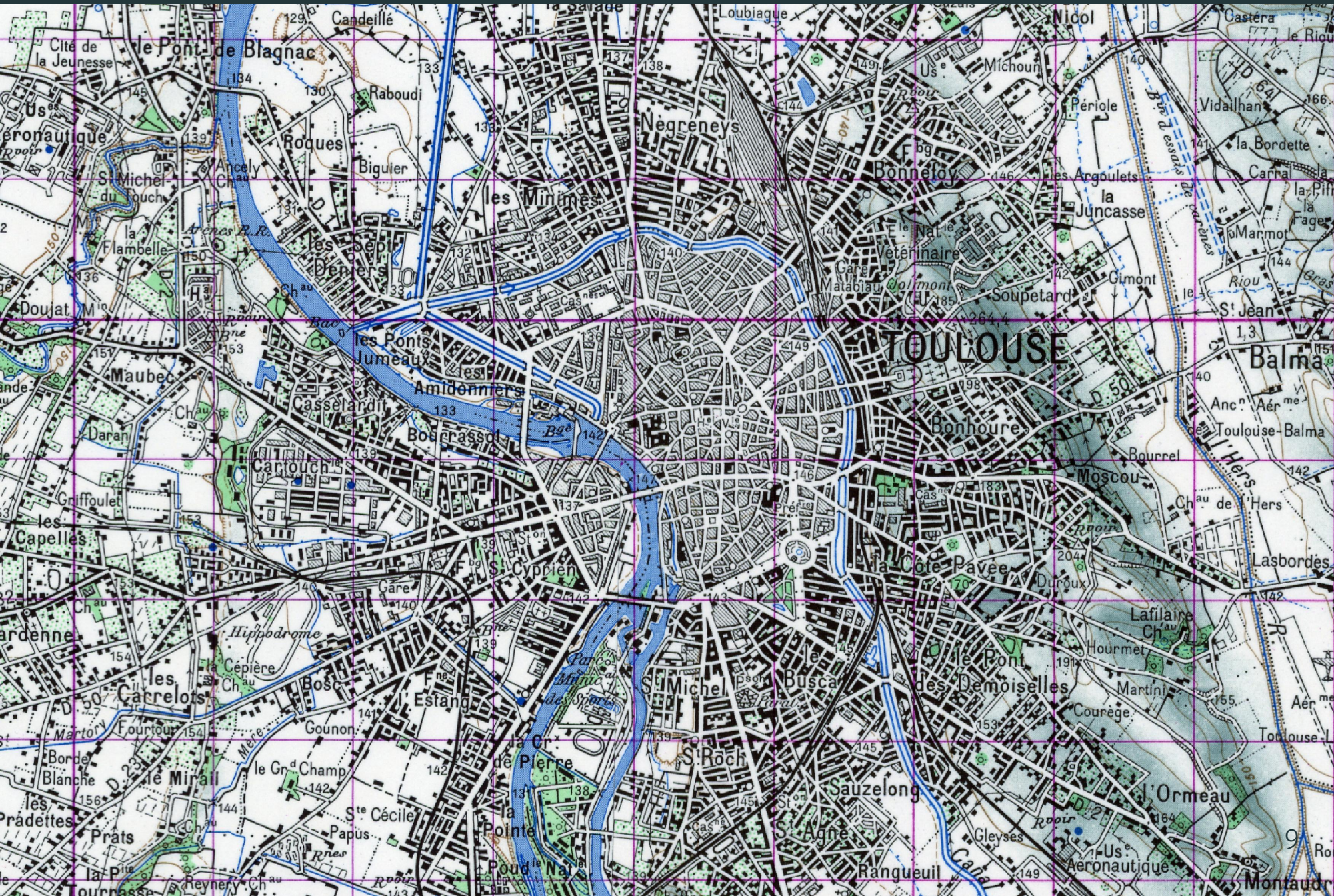
- Prediction tasks where parameter interpretability is not required and flexible methods are available
- The models fit flexible and generalisable functional forms to the data that were not defined in advance
- Naturally detect non-linearities and interactions among the inputs and handle high-dimensional problems

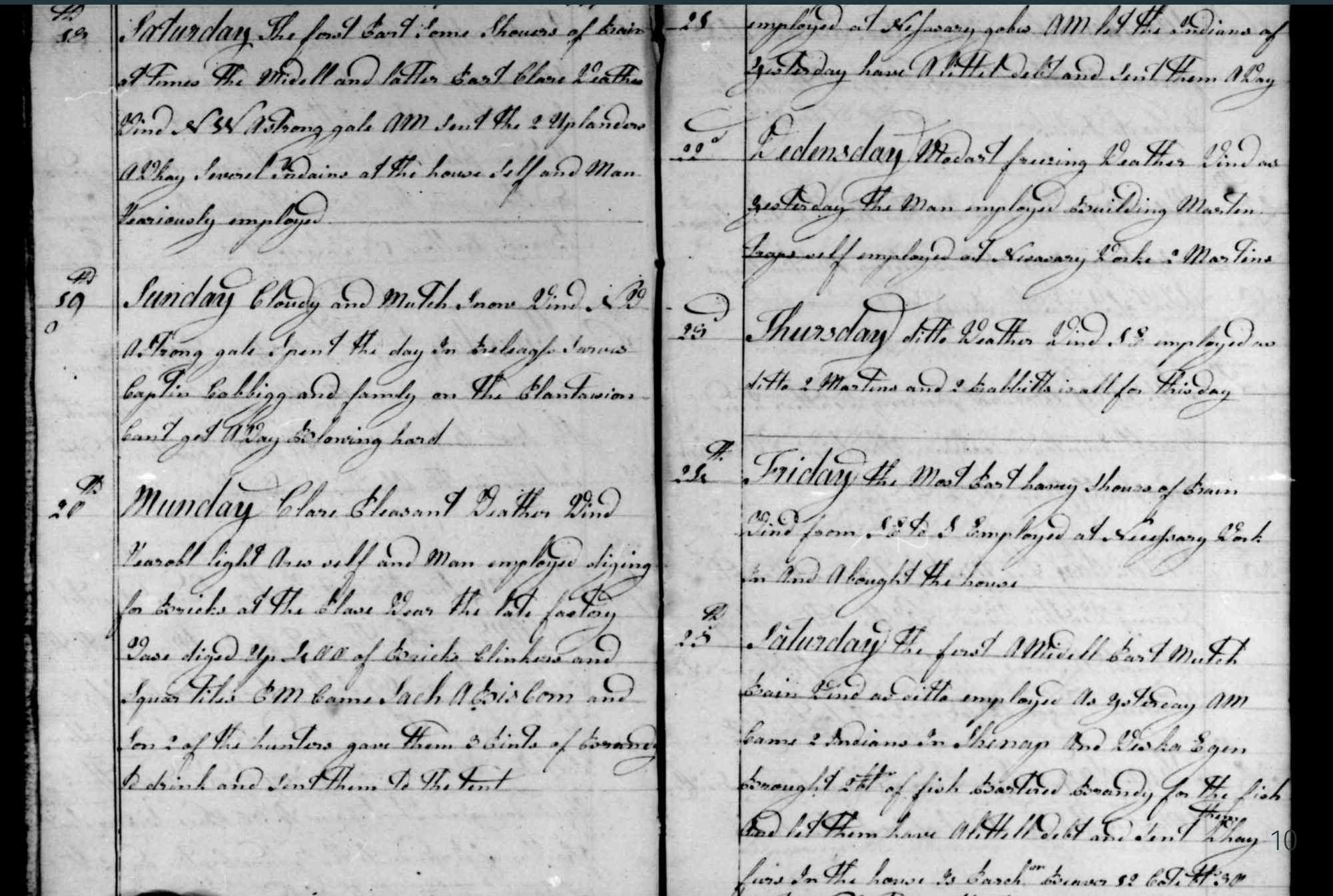
Sources and applications

Satellite images



Street view


TOULOUSE
le Pont de Blagnac
Cité de la Jeunesse
Raboudi
Roques
Biguier
Negreneys
Nicol
Michoun
Périole
Vidailhan
la Bordette
Bonnefoy
les Argoulets
la Juncasse
St Michel du Touch
les Minimes
les Sept Deniers
la Flambelle
Doujat
Soupetard
Cimont
St Jean
les Ponts Jumeaux
les Amidonniers
Maubec
Casselardit
Bourrassol
Cartouch
Daran
Bonhoure
Moscou
Bourrel
Balma
Griffoulet
les Capelles
St Cyprien
la Côte Pavée
Lasbordes
Hippodrome
la Cépière
les Carrelots
Fourtoul
Gounon
Lafilaire
Hourmet
le Pont des Demoiselles
Martini
Courège
Borde Blanche
le Mirail
le Grand Champ
les Pradettes
Prats
Ste Cécile
Papus
la Pointe
St Michel
St Roch
Sauzelong
St Agne
l'Ormeau
Gleyses
Rangueuil
Us Aéronautique
Montaudr



th 18 Saturday The first Part Some Shouers of Rain at Times the Midell and latter Part Clare Weather Wind N W A Strong gale AM Sent the 2 Uplanders A Way Severel Indains at the house Self and Man Veariously employed

th 19 Sunday Cloudy and Mutch Snow Wind N W A Strong gale Spent the day In Releagss Sarves Captin Cabbigg and family on the Plantaision Cant get A Way Blowing hard

th 20 Munday Clare Pleasant Weather Wind Vearobl light Ares self and Man employed diging for Bricks at the Place Wear the late factory Wase diged Up 1400 of Bricks Clinkers and Squar tiles PM Came Sach A Bis Com and Son 2 of the hunters gave them 3 Pints of Brandy to drink and Sent them to the tent

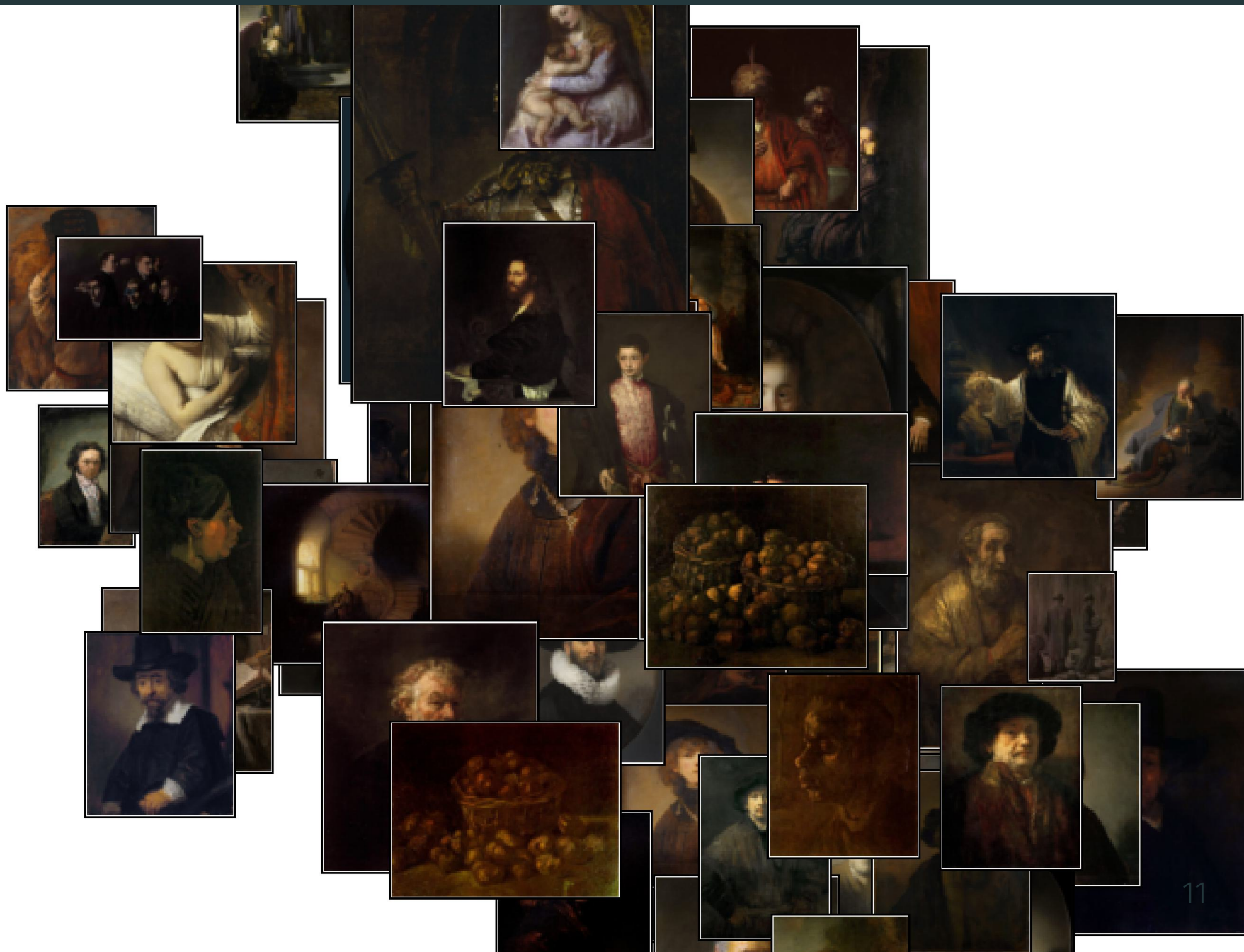
21 employed at Nesasary gobes AM let the Indians of Yesterday have A little debt and Sent them A Way

22d Wedensday Modart freezing Weather Wind as Yesterday the Man employed Building Marten traps self employed at Nesasary Worke 2 Martins

23d Thursday ditto Weather Wind S E employed as ditto 2 Martins and 2 Rabbitts is all for this day

th 24 Friday the Most Part havey Shours of Rain Wind from S E to S Employed at Necessary Work In And Abought the house

th 25 Saturday the first A Midell Part Mutch Rain Wind as ditto employed As Yesterday AM Came 2 Indians In Shenap And Weska Egen Brought 2 bl of fish Bartered Brandy for the fish And let them have A little debt and Sent them A Way furs In the house Is Parch.m Beaver 12 Cote bl 30



Task	Input	Output
Image level		
Regression	Image	$\rightarrow$ Numbers / probas
Captioning	Image	$\rightarrow$ Description
Representations	Image	$\rightarrow$ Vector
Sub-image level		
Localisation	Image	$\rightarrow$ Boxes & classes
Segmentation	Image	$\rightarrow$ Masks
Optical char. recog.	Image	$\rightarrow$ Text

Other applications: Image generation, Keypoints detection, Style transfer, Super-resolution, Inpainting ...

Task	Reference
Image regression	Chi et al. (2022)
Image classification	Voth and Yanagizawa-Drott (2025)
Object localisation	Caprini (2025)
Object segmentation	Gorin et al. (2025)
Change detection	Mueller et al. (2021)
Image generation	Astier and Lippmann (2025)
Optical character recog.	Carlson et al. (Working Paper)

Chi et al. (2022): "Microestimates of wealth for all low- and middle-income countries". Voth and Yanagizawa-Drott (2025): "Cultural Change through High School Portraits: Evidence from American Yearbooks". Caprini (2025): "Visual Bias". Gorin et al. (2025): "Measuring land use changes by (machine) learning from historical maps". Mueller et al. (2021): "Monitoring War destruction from space: A machine learning approach". Carlson et al. (Working Paper): *Efficient OCR for Building a Diverse Digital History*. Astier and Lippmann (2025): "Gender Differences in Visual Communication in Politics".

Overview

Schedule

#	Lecture	Prof.
1.	Image data for development economics	Lisa
2.	Predictive modelling	Clément
3.	Neural networks	Clément
4.	Image processing and GIS fundamentals	Clément
5.	Convolutional networks	Clément
6.	Image modelling applications	Clément

Resources

Learning material

- The EPI contains lectures, practical exercises, datasets, papers, and other resources
- Files are updated right before every session so make sure to download the latest version in class

Computer resources

- Individual computer with administrator rights and a working internet connection
- Google Colab or Anaconda / Miniconda Python 3.12, with a development environment e.g. VSCode, PyCharm

For a local installation, create a separate virtual environment for the course, which you can remove afterwards

- Neural networks are implemented using PyTorch, available in CPU or GPU-optimised versions
- For GPU support, use either Cuda (NVDIA) or Metal (M-chip) depending on your hardware

```
conda create -n imageanalysis python=3.12
conda activate imageanalysis
conda install -c conda-forge -y matplotlib pandas [...]
```

- Hastie, Trevor, Robert Tibshirani, and Jerome Friedman (2009). ***The elements of statistical learning.*** Springer.
- Nielsen, Michael A. (2015). ***Neural networks and deep learning.*** Determination Press.
- Goodfellow, Ian, Yoshua Bengio, and Aaron Courville (2016). ***Deep Learning.*** MIT Press.

- Breiman, Leo (2001). **“Statistical modeling: The two cultures”.** In: *Statistical Science* 16.3, pp. 199–231.
- LeCun, Yann, Yoshua Bengio, and Geoffrey Hinton (2015). **“Deep learning”.** In: *Nature* 521, pp. 436–444.
- Mullainathan, Sendhil and Jann Spiess (2017). **“Machine learning: An applied econometric approach”.** In: *Journal of Economic Perspective* 31.2, pp. 87–106.
- Naik, Nikhil et al. (2017). **“Computer vision uncovers predictors of physical urban change”.** In: *Proceedings of the National Academy of Sciences* 114.29, pp. 7571–7576.

- Lones, Michael A. (2021). **“How to avoid machine learning pitfalls: A guide for academic researchers”.** In: *CoRR* abs/2108.02497.
- Mueller, Hannes et al. (2021). **“Monitoring War destruction from space: A machine learning approach”.** In: *Proceedings of the National Academy of Sciences* 118.23.

Thank you for your attention!