



**TEN YEARS OF *IN CODICE RATIO*:
REFLECTIONS ON KNOWLEDGE ACQUISITION AND
TEACHING METHODOLOGIES**

A long time ago in a galaxy far,
far away....

2016 - 2018



In Codice Ratio

Target

In Codice Ratio

Techniques

XLVII

```
static unsigned px(unsigned py, unsigned pixel, int offset)
{
    // Decode the color index (with de-emphasis bits).
    // We need 8-bit values, to produce a RGB value, we emulate the NTSC circuitry.
    // For most cases, this is described as:
    // http://wiki.neudev.com/?index.php/NTSC_video
    // Note that this is not a table of 64*8 RGB values.
    static unsigned palette[64][3] = {0}, prev = 0;
    // Caching the generated colors to avoid
    if (prev == 0)
    {
        // Decode the color index.
        int c = pixel / 16, l = c < 0xE ? pixel / 4 & 12 : 4, e = pixel / 64, y = 0, i = 0, q = 0;
        // Calculate the sum and threshold by emulating the relevant circuits:
        auto s = "\378\378\32\305\35\311\330D\357\13D!>N";
        for (int p = 0; p < 12; p++) // 12 samples of NTSC signal constitute a color.
        {
            // NBS NTSC modulator (image wave between up to four voltage levels):
            int b = 40 + s[(c > 12 * ((c + 8 + p) % 12 < 6)) + 2 * ((0451326 >> p / 2 * 3 & e) + 1)];
            // Use in the NTSC demodulator:
            y += b;
            i += b * int(std::cos(M_PI * p / 6) * 5909);
            q += b * int(std::sin(M_PI * p / 6) * 5909);
        }
        // Convert the YIQ color into RGB
        auto gammafix = [=](float f) { return f <= 0.f ? 0.f : std::pow(f, 2.2f / 1.8f); };
        auto clamp = [=](int v) { return v > 255 ? 255 : v; };
        // Store color at subpixel precision.
        + 0x10000 * clamp(255 * gammafix(y / 1980.f + i * 0.947f / 9e6f + q * 0.624f / 9e6f));
        + 0x00100 * clamp(255 * gammafix(y / 1980.f + i * -0.275f / 9e6f + q * -0.636f / 9e6f));
        + 0x00001 * clamp(255 * gammafix(y / 1980.f + i * -1.109f / 9e6f + q * 1.709f / 9e6f));
    }
    // Store the RGB color into the frame buffer.
    ((u32*) s->pixels)[py * 256 + px] = palette[offset][prev % 64][pixel];
    prev = pixel;
}

void FlushScanline(unsigned py)
{
    if (py == 239) SDL_Flip(s);
}
```

ML for Handwritten Text Recognition

Machine Learning techniques are effective for Handwritten Text Recognition (HTR) tasks

Machine Learning needs (a lot of) training data:
examples to teach the system how to accomplish a task

For HTR, training data consist of images of many different portions of the document (e.g., words, lines) and their associated transcription

Main Machine Learning Problem

- How to produce the training data
- We experimented two approaches:
 - Crowd-based: we exploited **non-expert persons** (many and not skilled)
 - Qualified-expert: we relied on **professional paleographers** (very few and rather busy)

Crowd-based Approach

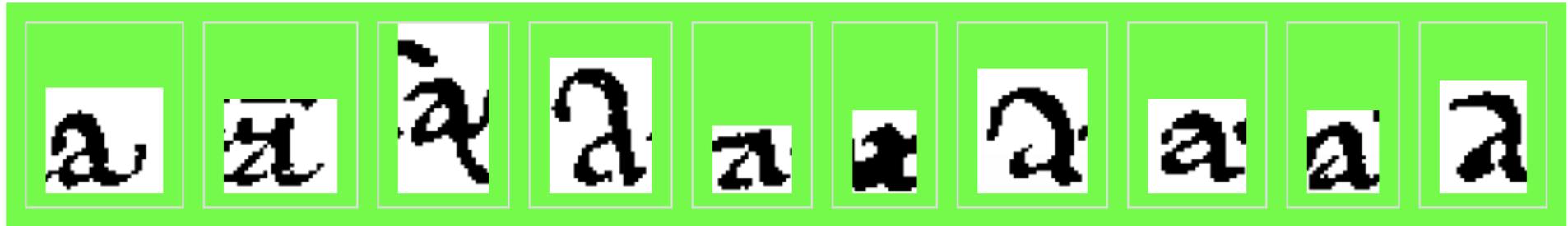
Goal: leverage a crowd of non-experts (high school students) to produce training data

Problem: they cannot read words or lines entirely

Solution:

- Propose to the crowd a simple task:
recognize symbols (not words or lines) based on pattern matching
- Algorithmic approach based on language model to aggregate candidate transcriptions

Mark the strokes that give rise to a symbol that is similar to the samples in the green area



RESTART

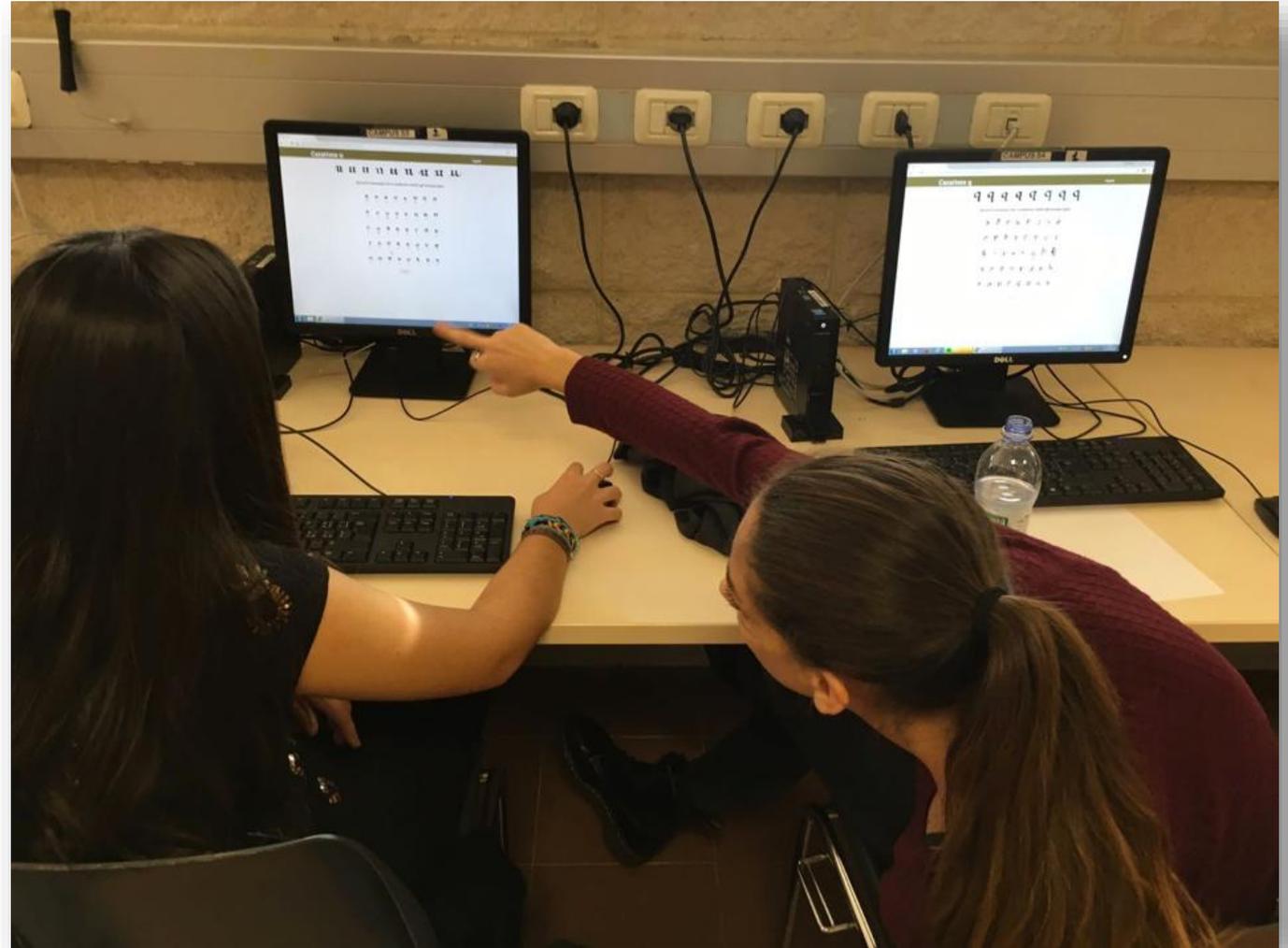
UNDO

CONFIRM

Students provided labels to ML

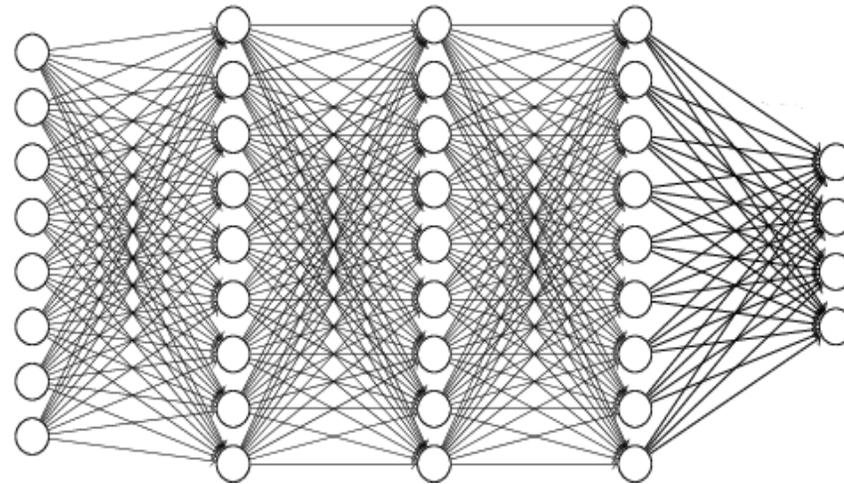
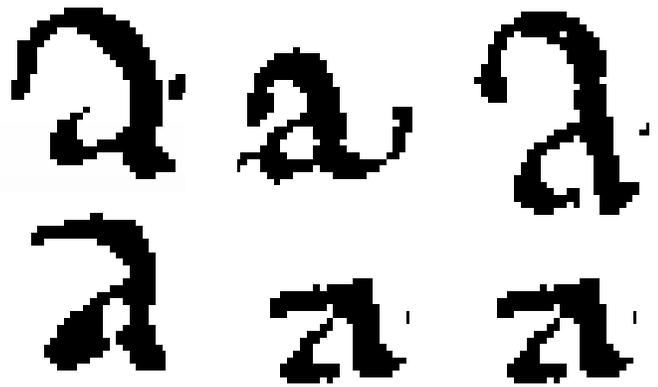
700 students
from 26 schools

10M images processed



We trained an Artificial Neural Network
with the examples produced by the students

Samples for a



Results (intuition)

On a page of 296 words:

62%: correct transcription (**green**)

20% at edit distance 1 (**yellow**)

18% not processable (**gray**)

Failures due to:

Segmentation errors (many)

Symbol recognition errors (a few)

na. Et si quis de hominib; exatus ut ecclie pragen. furtu. ul rapina. ul alia
huiuscemodi grandem culpam perpetraverit perpetrato. criminis sententia Regie
potestatis subiaceat. et pragen ecclia ut exatus cu homo erit ipius uendicat
facultates. Si quis etiam in bonis exatus ut ecclie pragen homicidii psumpse-
rit perpetrare. et homicida euaserit. consanguinei interfecti reu iure terre per-
curant. ita tam qd hoies ecclie exatus conseruent iudempnes. Podiu etiam
qd aliquando eiusde fuit ecclie cu omib; iurib; suis. accessionib; 7 ptinentijs
de regia munificentia eidem ecclie concedimus 7 donamus. Ad huius igitur nre
restauracionis. concessionis. 7 donatois notitia et inuolabile firmitati. coram
infra positis testib; presens priuilegiu p manu Hermannj Notarij et Capellan
nri fecimus fieri. et ipm sigilli nri munimine mandauimus insigniri. Anno
dnice Incarnatois. m. cc. xxii. vi. Non. Julij. Indict. viij. in monte Seac pre-
sidente in Romana ecclia dno Honorio tertio Regnante uero in Impio dno
friderico. in presentia domini Gregorij de crescentio Sancti theodori diae Card
ap. se. le. Testes aut sunt hui. dominus Robertus eps Olomucen. dominus
Johs Nitraen eps. dominus Laurentius Wirtzslauen eps. dñs Lupold Austrie
et Stire Dux. Comes Conradus de ardel. dñs puppo prepositus Bambergem.
Duhomil Abbas de Breimou. Hermannus abbas de Wilalmou. Rimerus abbas
de Insula Johs abbas de Gradist. Bertoldus abbas de Stragou. Gerlacus abbas
de oulesk. Wilelmus abbas de Siloa. Hermannus abbas de Lucomiks. Boni-
fatus abbas de Gradist. Florianus abbas de luca. Wernerus abbas scē Crucis.

2019-2021



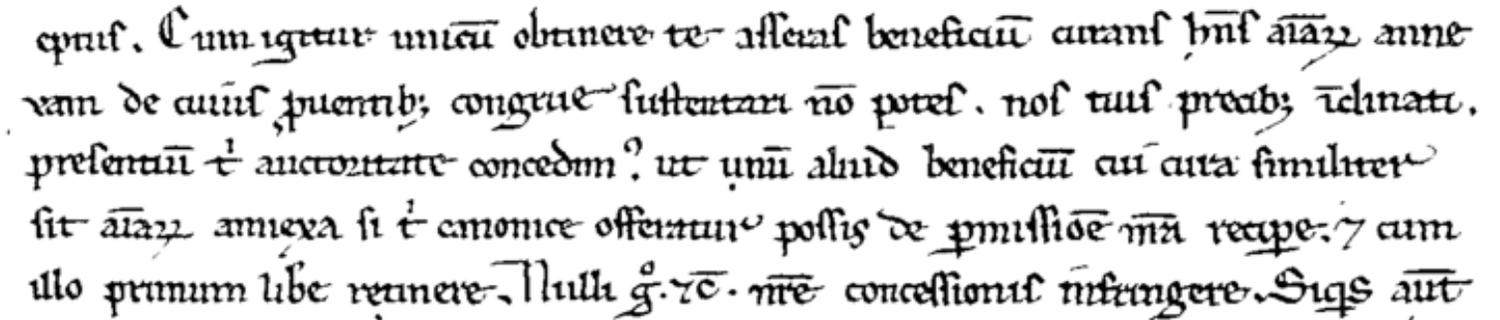
In Codice Ratio

Qualified-expert Approach

ML needs
training data

Let us teach contextual
visual and language
knowledge

Hey AI, these lines



ceptus. Cum igitur unicū obtinere te asseras beneficiū curans hñs aīaz anne-
xam de cuius puentib; congrue sustentari nō potes. nos tuis precib; inclinati.
presentiū t̄ auctoritate concedim⁹. ut unū aliud beneficiū cui cura similiter
sit aīaz annexa si t̄ canonice offeratur possis de pmissiōe nra recipere. ⁊ cum
illo primum libe retinere. Nulli ḡ. rē. nre concessionis infringere. Sigs aut̄

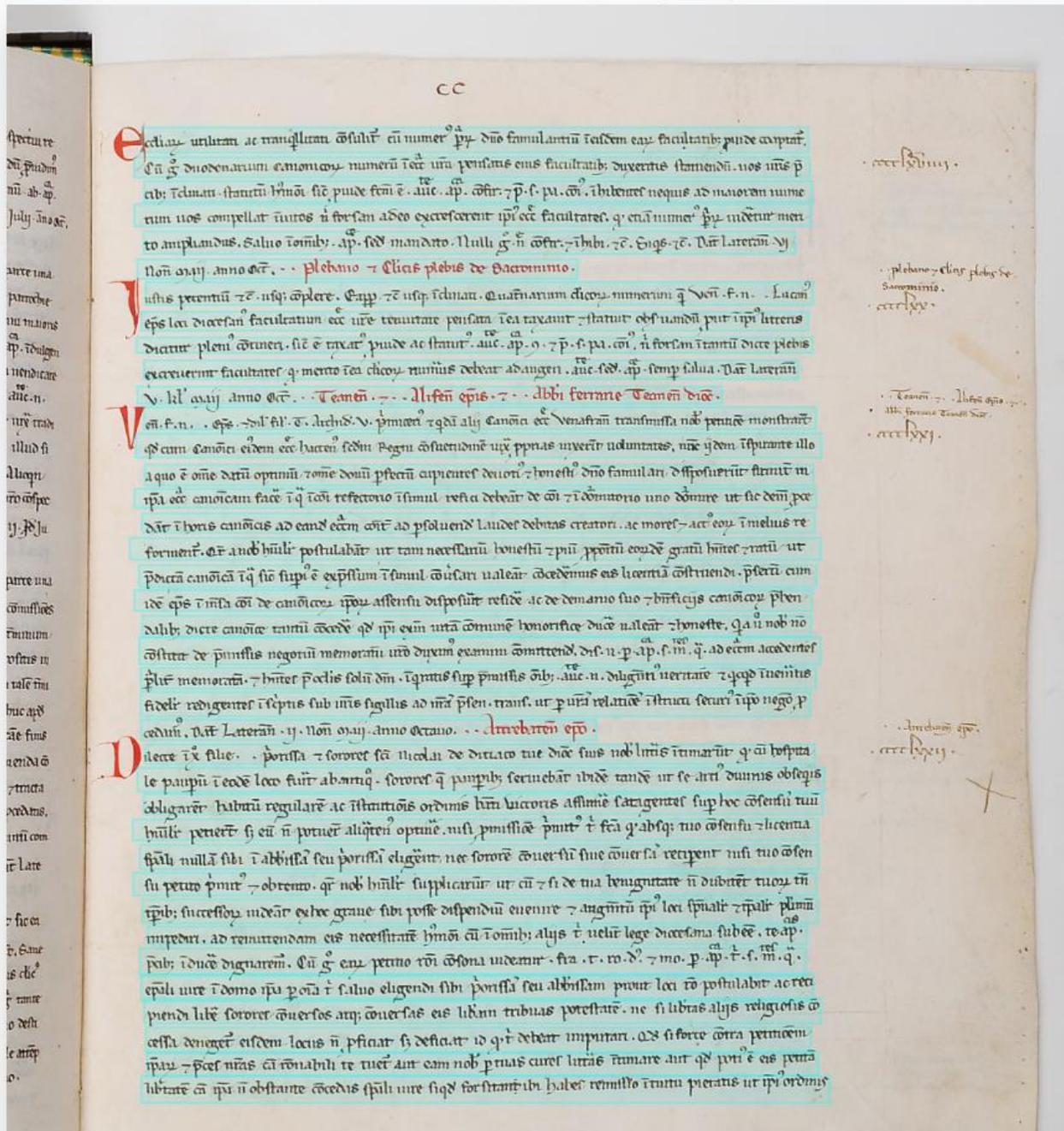
correspond to

-eptus. Cum igitur unicu(m) obtinere te asseras beneficiu(m) curans h(abe)ns a(n)i(m)ar(um) anne-
xam de cuius p(ro)ventib(us) congrue sustentari no(n) potes nos tuis precib(us) i(n)clinati
presentiu(m) t(ib)i auctoritate concedim(us) ut unu(m) aliud beneficiu(m) cui cura similiter
sit a(n)i(m)ar(um) annexa si t(ib)i canonice offeratur possis de p(er)missio(n)e n(ost)ra recip(er)e et cum
illo primum lib(er)e retinere. Nulli (er)go et c(etera) n(ost)re concessionis infringere. Siq(ui)s aut(em)

Supporting the production of training data

The production of this kind of training data is a time-consuming activity that requires the intervention of expert paleographers and/or diplomatists

Francesca Gallo, Pos-doc, Roma Tre University



Choose File No file chosen Upload GT

Confirm Current File Annotation

- Ecc(les)ia(rum) utilitati ac tranq(ui)llitati co(n)sulit(ur) cu(m) numer(us) p(er)sonarum d(omi)no famulantiu(m) i(n) eisdem ea(rum) facultatib(us) p(ro)vide coapat(ur)
- Cu(m) (er)g'o' duodenarium canonicor(um) numeru(m) i(n) ecc(lesi) 'a' v(est)ra pensatis eius facultatib(us) duxeritis statuendu(m) nos v(est)ris p(re) cib(us) inclinati statutu(m) h(uius)mo(d)i sic(ut) p(ro)vide f(a)c(tu)m e(st) auc(toritate) ap(ostolica) co(n)firm(amus) (et) p(raesentis) s(cripti) pa(trocinio) co(mmun)i(mus) i(n)hibentes ne quis ad maiorem nume rum vos compellat i(n)vitos n(isi) forsam adeo exerescent ip(s)i(us) ecc(lesie) facultates q(uod) etia(m) numer(us) p(er)sonarum vide(a)tur meri
- to ampliandus salvo i(n) om(n)ib(us) ap(ostolice) sed(is) mandato Nulli (er)g(o) n(e) co(n)fir(mamus) (et) i(n)hibi(mus) (et)c(etera) Si q(ui)s (et)c(etera) Dat(um) Lateran(i) .VI.
- Non(as) Maii anno Oct(avo) Plebano (et) Cl(er)icis plebis de Sacrominio
- (I)lustis petentiu(m) (et)c(etera) usq(ue) co(m)plere Eap(ropter) (et)c(etera) usq(ue) i(n)clinati Quat(er)narium cl(er)ico(rum) numerum q(ue)m ven(erabilis) f(rater) n(oster) Lucan(us)
- ep(iscopu)s loci diocesan(us) facultatum ecc(lesia)e v(est)re tenuitate pensata i(n) ea taxavit et statuit obs(er)vandu(m) p(ro)ut i(n) ip(s)i(us) litteris dicitur pleni(us) co(n)tineri sic(ut) e(st) taxat(us) p(ro)vide ac statut(us) auc(toritate) ap(ostolica) con(firmamus) et p(raesentis) s(cripti) pa(trocinio) co(mmun)i(mus) n(isi) forsam i(n) tantu(m) dicte plebis excreverint facultates q(uod) merito i(n) ea cl(er)ico(rum) num(er)us debeat ad augeri auc(toritate) sed(is) ap(ostolice) semp(er) salva Dat(um) Lateran(i)
- V. K(a)l(endas) Maii anno Oct(avo) Teanen(sis) (et) Alifen(sis) ep(iscopu)s (et) Abb(at) ferrarie Teanen(sis) diocesis
- Ven(erabilis) f(rater) n(oster), Ep(iscopu)s (et) dil(ecti) fil(ii) n(ostri) Archid(iaconus) .V. P(ro)vic(er)i(us) (et) q(ui)da(m) alii cano(n)ici ecc(lesie) Venafra(n)sis transmissa no(m)ina etia(m) te monstrar(un)t q(uod) cum cano(n)ici ei(us)dem ecc(lesi) 'e' hacten(us) s(e)c(un)d(u)m Regni co(n)suetudine(m) i(n) p(ro)vinciis cano(n)icis voluntates nu(nc) iidem i(n)spiciunt illu
- a quo e(st) om(n)e datu(m) optimu(m) (et) om(n)e donu(m) p(er)fectu(m) cupientes devoti(us) (et) honesti(us) d(omi)no famulari dssposuer(unt) firmit(er) in
- ip(s)a ecc(lesi) 'a' cano(n)icam fac(er)e i(n) qu(a) i(n) co(mmun)i refectorio i(n)simul refici debeat de co(mmun)i (et) i(n) delectatione una de(m)erit ut eis deniq(ue) p(er)...

Annotations

An expert creates the transcription to train the system

ibide novella plantatio tuo favore suscipiat increm(en)tu(m)
 Dat(um) Lateran(i) Non(as) Maij Anno Oct(avo) § In e(odem)

m(od)o sc(r)'ip(tum) e(st) Abb(at)i (et) P(r)'ori s(an)c(t)i Aub(er)ti
 (et) Cantori Cameracen(s)i verbis co(m)petent(er) mutatis ut
 ip(su)m ep(iscopu)m ad

id mon(er)e prudent(er) debea(n)t (et) efficacit(er) i(n)duc(er)e
 p(ro)cure(n)t De Strada Cister(cens)is ord(in)is (et)
 Fructuarien(sibus) Abb(at)ib(us)

{A}d reformandu(m) statu(m) quonda(m) nobilis Monasterij
 Secusien(sis) (et) P(re)po(s)ito Carien(s)i Taurinen(sis) (et)
 Yporien(sis) dioc(esum)

q(uo)d Monachor(um) ip(s)i(us) loci detestanda p(er)v(er)sitas
 enormit(er) deformavit (et) ignobile reddidit ap(ostoli)'ca' sedes ad
 q(u)'a'(m) Mona-

steriu(m) idem noscitur i(m)mediate spectare multotiens sollicitate
 laboravit s(ed) usq(ue) ad eo exuberavit (et) exube-

rat monachor(um) eor(um)de(m) malitia ut nulla diligentia co'r(r)igi
 potuerit eor(um) p(er)v(er)sitas nullo studio potu(er)it ip(s)i(us)

loci deformitas reformari Deniq(ue) cu(m) fe(l)icis me(m)orie
 Innoc(entii) p(a)p(e) p(re)deces(s)oris n(ost)ri cura sollicita om(ne)s
 aut fere om(ne)s ip(s)i(us)

loci monachos p(ro)p(ter) suos multiples (et) enormes excessus
 amoveri fecerit ab eodem (et) alios de div(er)sis locis in

ip(su)m monasteriu(m) i(n)troducti speratis q(uo)d v(e)l sic posset
 ip(su)m monasteriu(m) reformare hij qui sic amoti fuera(n)t

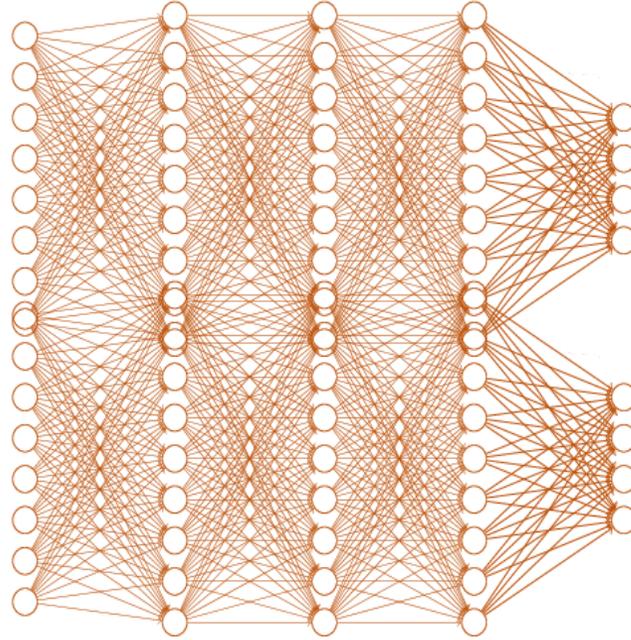
ad monasteriu(m) ip(su)m v(e)l occ(asi)one litt(er)ar(um) a sed(e)
 ap(ostoli)'ca' p(er) exp(re)ssu(m) m(en)daci(u)m optentar(um) v(e)l
 laicor(um) i(m)p(re)ssio(n)e regressi solita

i(n) eo malitia sic(ut) nup(er) accepim(us) debachant(ur) factis int(er)
 se colligatio(n)ib(us) ac iuram(en)to firmatis (et) ut brevit(er) con-

cludam(us) Monasteriu(m) ip(su)m alienatis magnis (et) nobilib(us)
 poss(essi)onib(us) ei(us) (et) distractis (etiam) libris ac alijs
 ecc(lesi)a'sticis

ornam(en)tis ad ei(us) desolatio(n)is miseria(m) deduxer(it) ut ubi
 magnus honorabilisq(ue) Co(n)vent(us) co(n)sueverat i(n) neces-

sarior(um) habundantia d(omi)no famulari nu(n)c pauci Monachi solo
 no(m)i(n)e seu larve poti(us) Monachor(um) in bonor(um)



Trained Network



corpis infirmitate detentus et Egidio clerico excommunicato et interdicto licet extra terram

corporis infirmitate detentus et Egidio clerico excommunicato et interdicto licet extra terram

eandem beneficium contulisti dilectus filius noster J. tituli sancte Praxedis presbiter Cardinalis tunc apostolice sedis legatus

eandem beneficium contulisti dilectus filius noster J. tituli sancte Praxedis presbiter Cardinalis tunc apostolice sedis legatus

te asserens ex promissis excommunicationis sententiam incurrisse a qua sententiam te absoluit a pontificalibus

te asserens ex promissis excommunicationis sententiam incurrisse a qua sententiam te absoluit a pontificalibus

collatione beneficiorum ac a sententia promulganda in tuos subditos sine tui consensu Ca

collatione beneficiorum ac a sententia promulganda in tuos subditos sine tui consensu Ca

periculi te suspendit. Cum autem at asseris ex suspensione huiusmodi Amicleni ecclesie grave

periculi te suspendit Cum autem at asseris ex suspensione huiusmodi Amicleni ecclesie grave

immineat detrimentum te ac predicto Capitulo vix valentibus in unam sententiam convenire ac te

immineat detrimentum te ac predicto Capitulo vix valentibus in unam sententiam convenire ac te

celebrare sine pontificalibus in decem vicariis suspensione eandem de maiori relaxari maiori potest

Results

Training set

- 40 pages transcribed by a PhD student in paleography

Promising achievements:

- on average less than 8 errors per line
- most lines are perfect, errors are concentrated in a few lines: why?

lecte in x̄o filie. - p̄orissa ⁊ sorores sc̄i Nicolai de ditiaco tue dioc̄e suis nob̄ litteris intimarunt q̄ cū hospita

lecte in xristo filie **p**orissa et sorores sancti Nicolai de ditiaco tue diocesis suis nobis litteris intimarunt quod cum hospita

Automatically generated

lecte in **Chrost** filie **p**irisa et sorores sancti **N**ucolaa de ditiaco tue diocesis suis nobis litteris intimarunt quod cum hospita

We observed that in the training data



sometimes was solved as **xristo**, other times as **christo**



In Codice Ratio

Technology Transfer

ICR on a Smartphone

In a Technology Transfer Project with a local company we developed a solution to read fiscal documents

It is in production!



Google has selected
our research as
showcase project for
their AI platform



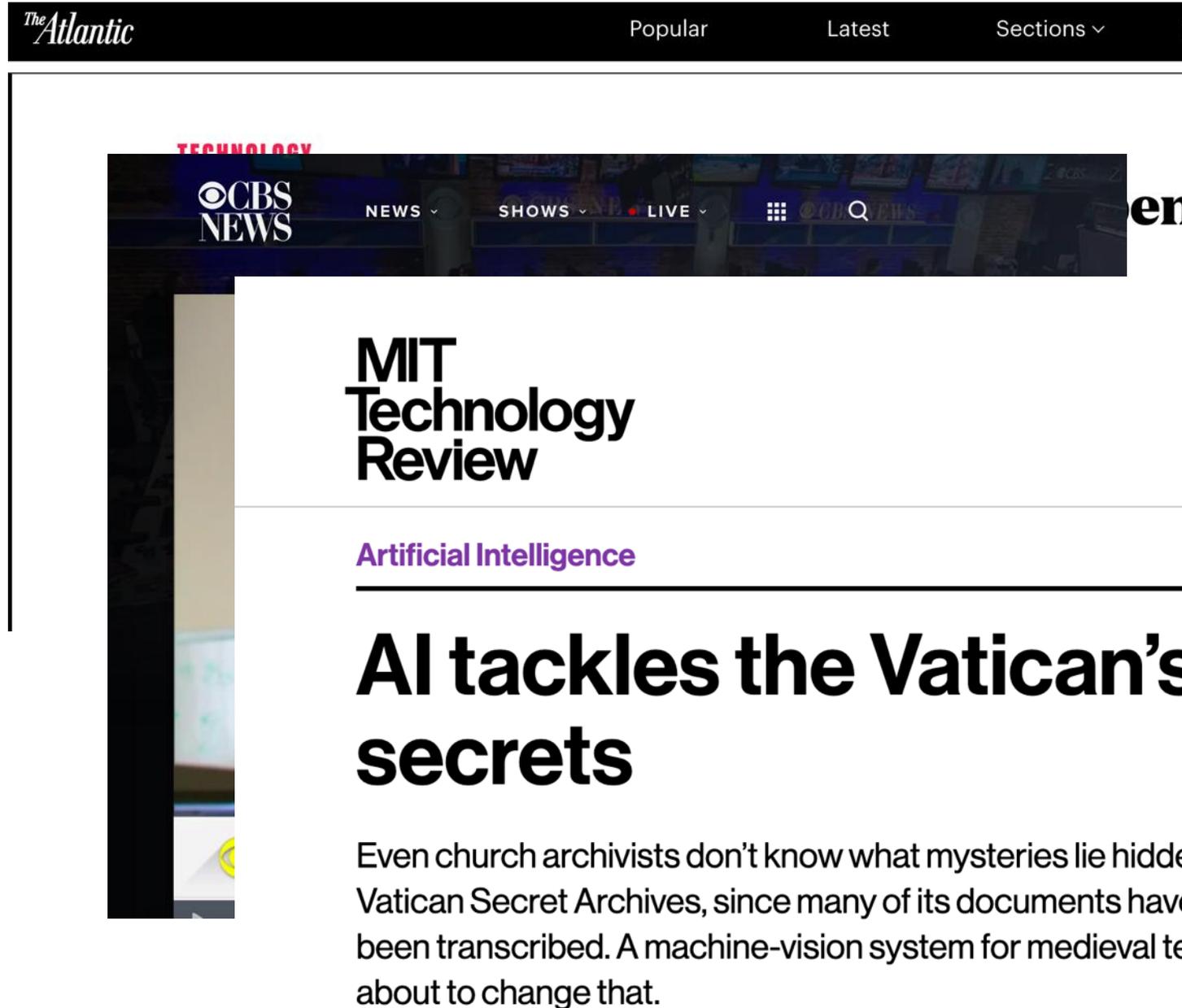
Developers

Helping paleographers transcribe
medieval text using TensorFlow

Watch the video 

<http://tensorflow.org>

Many news papers, magazines, and TVs reported our results



The image shows a screenshot of a news article from MIT Technology Review. At the top, there is a navigation bar for 'The Atlantic' with links for 'Popular', 'Latest', and 'Sections'. Below this is a 'CBS NEWS' banner with 'NEWS', 'SHOWS', and 'LIVE' options. The article title is 'MIT Technology Review' in large black font, followed by the sub-section 'Artificial Intelligence' in purple. The main headline is 'AI tackles the Vatican's secrets' in large, bold black font. The introductory text reads: 'Even church archivists don't know what mysteries lie hidden in the Vatican Secret Archives, since many of its documents have never been transcribed. A machine-vision system for medieval text is about to change that.'

The Atlantic Popular Latest Sections

TECHNOLOGY

CBS NEWS NEWS SHOWS LIVE

MIT Technology Review

Artificial Intelligence

AI tackles the Vatican's secrets

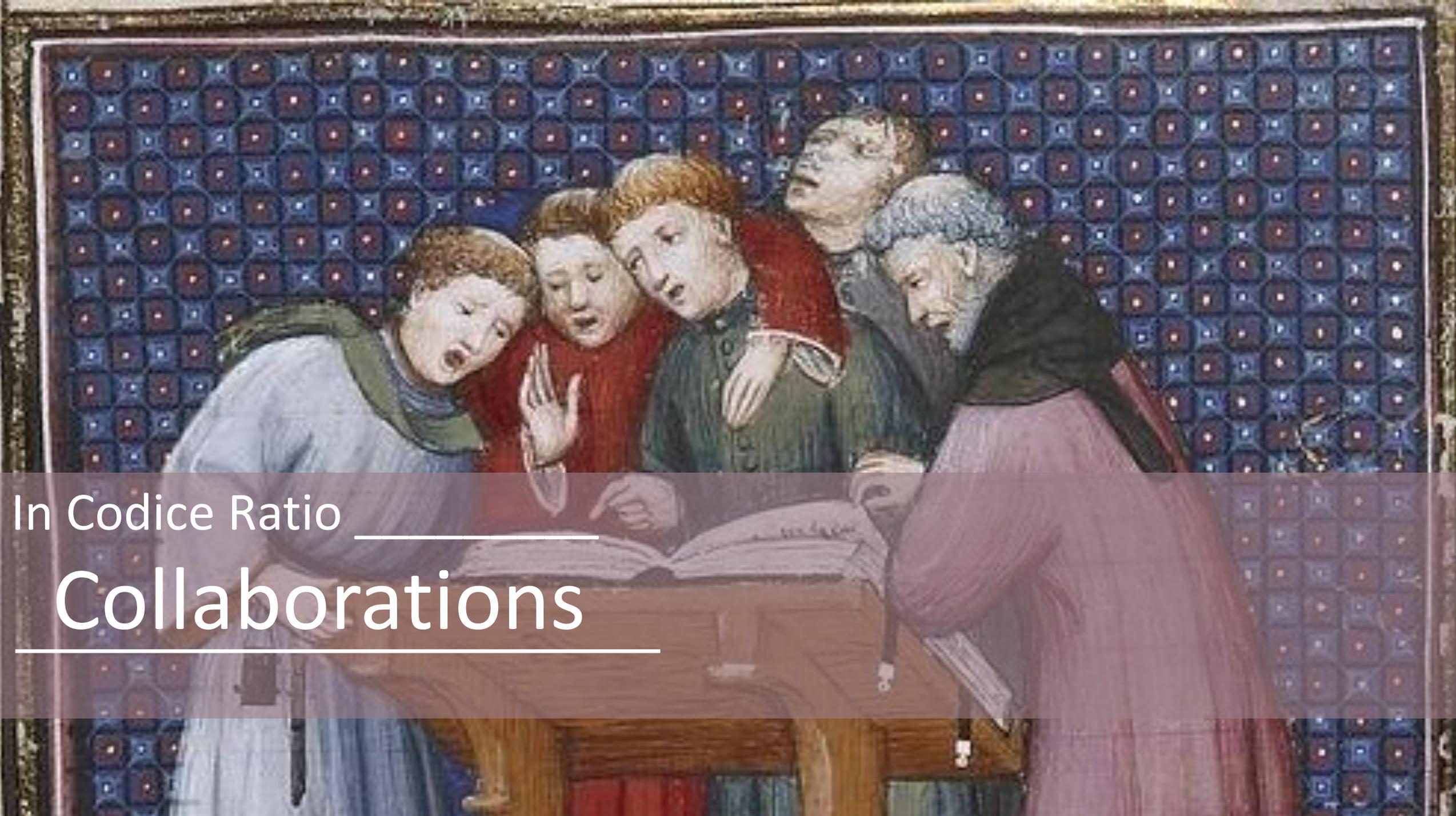
Even church archivists don't know what mysteries lie hidden in the Vatican Secret Archives, since many of its documents have never been transcribed. A machine-vision system for medieval text is about to change that.

Two students of our university have founded a startup to exploit the technology developed in the project



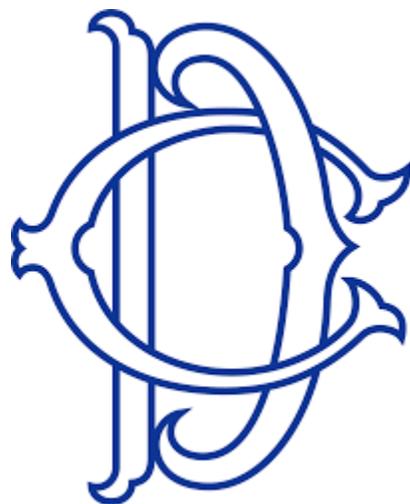
Their goal is to offer a service to automate data entry processes

Example of the problem: a small bank processes 2M fiscal documents every year. Data are entered manually!



In Codice Ratio _____
Collaborations

The Archive of the Chamber of Deputies





Surviving

Matrices is a sequel of the In Codice Ratio project, in collaboration with the **State Archive of Rome**.

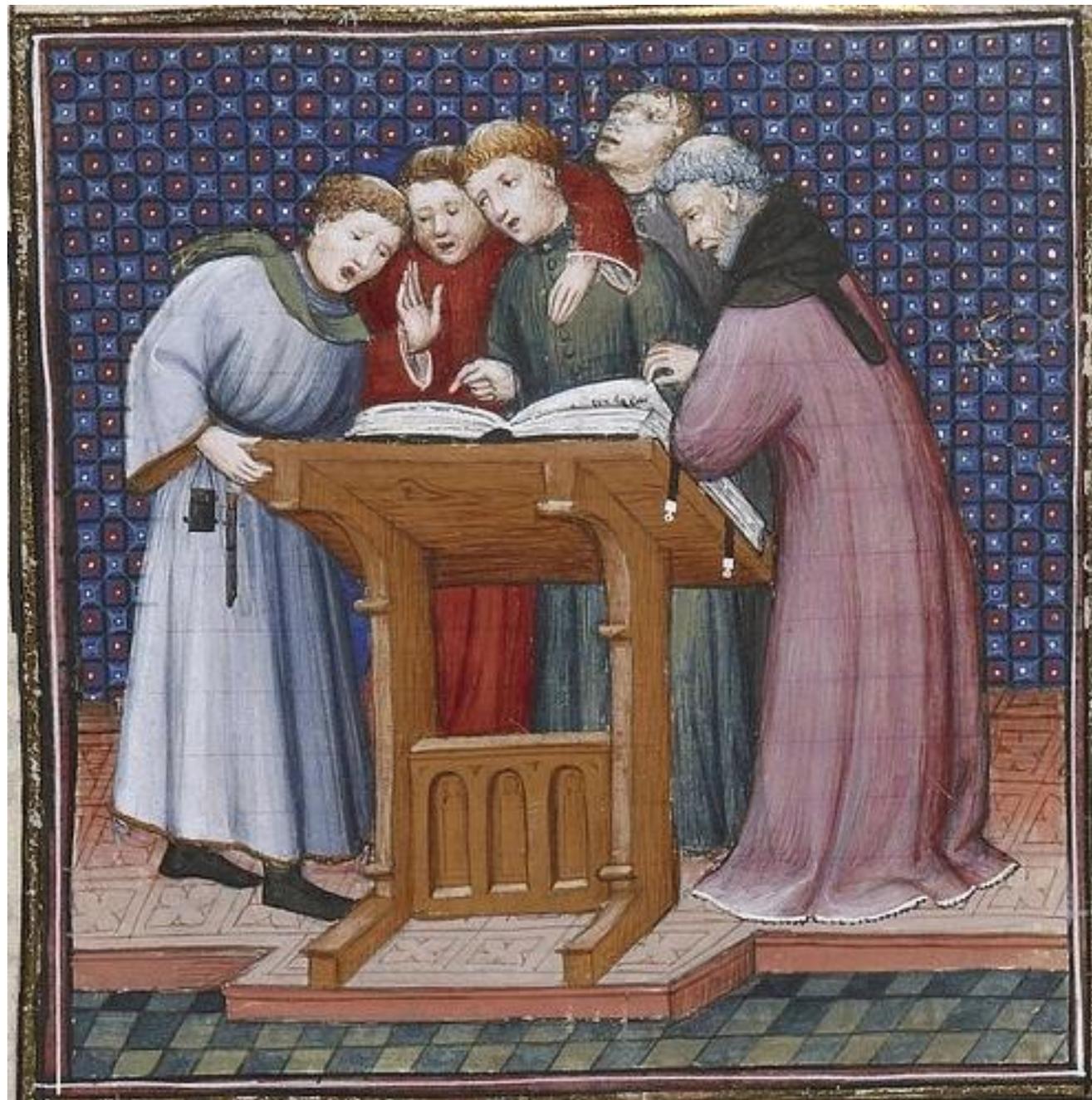


**Medieval documents from
SS. Cosmas and Damian in Mica Aurea**



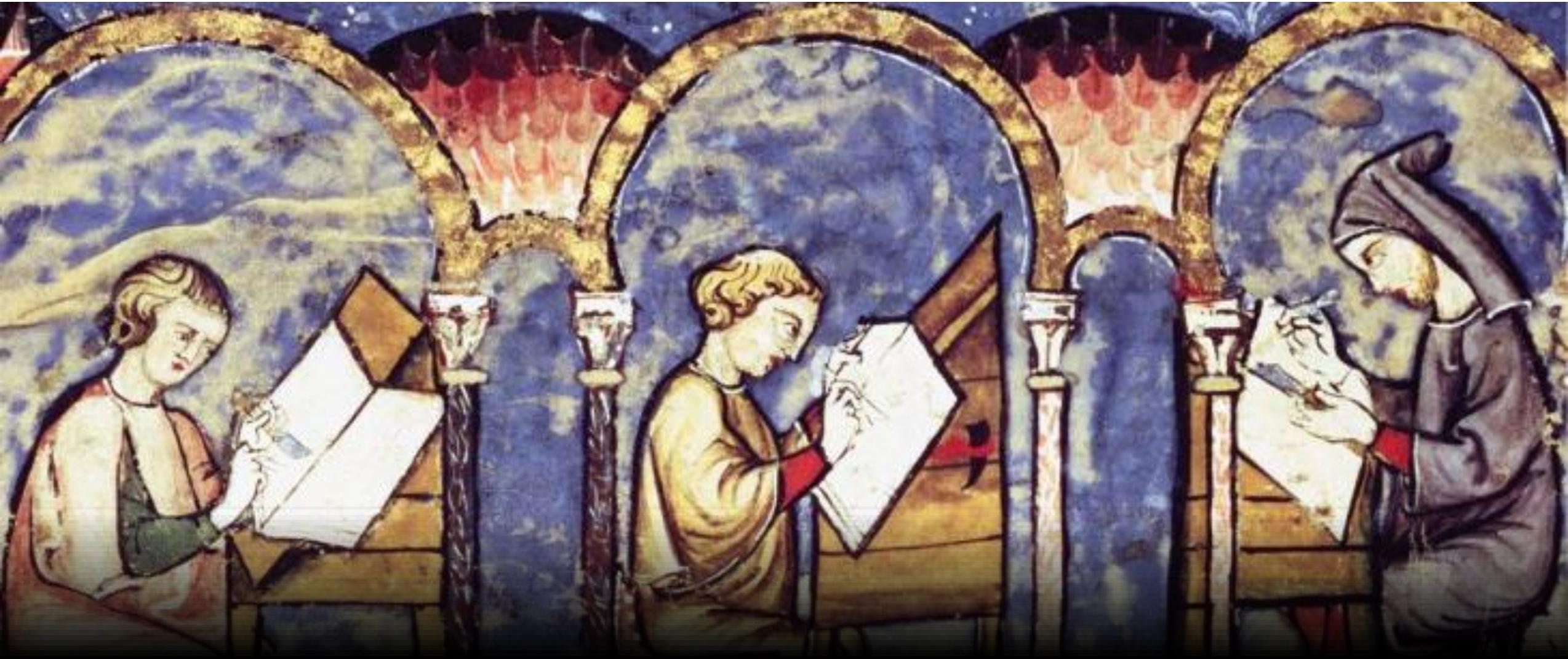


exceed one's own bounds

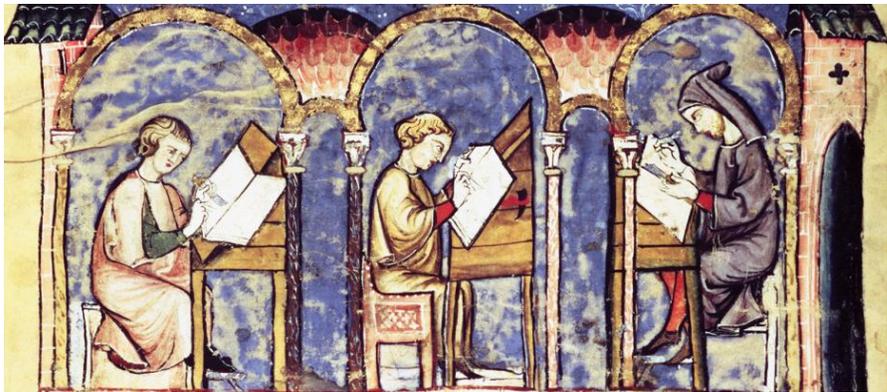


Paleographers and librarians must be "in-the-loop". Yes, but how?

2021-now

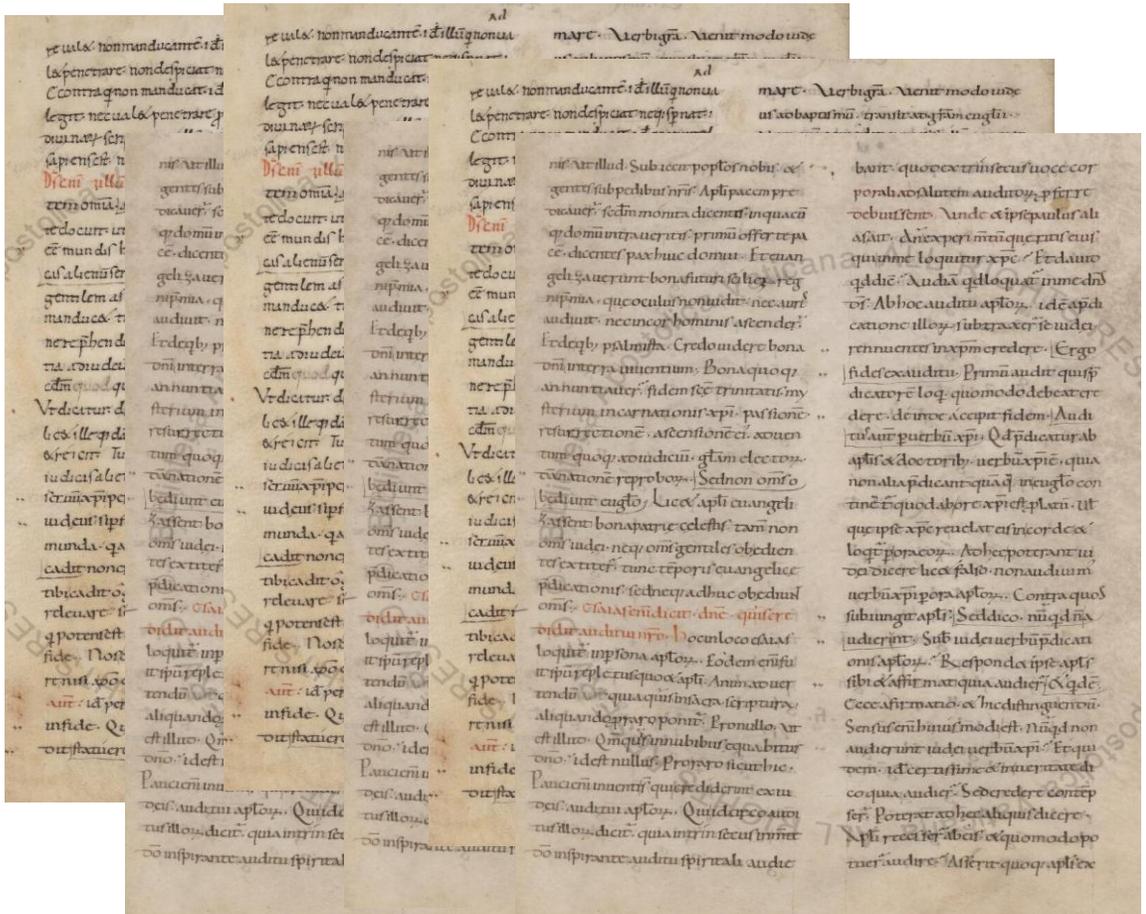


Automatic Handwriting Identification



Handwriting Identification

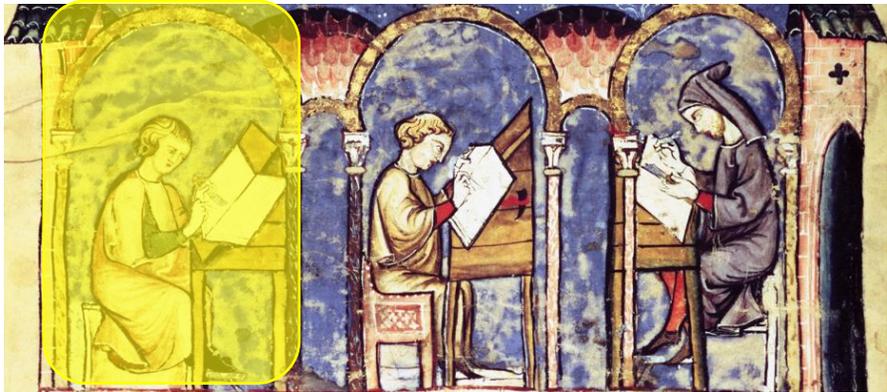
Handwriting identification is the challenging problem of attributing handwritten texts to specific scribes



Scribe 1

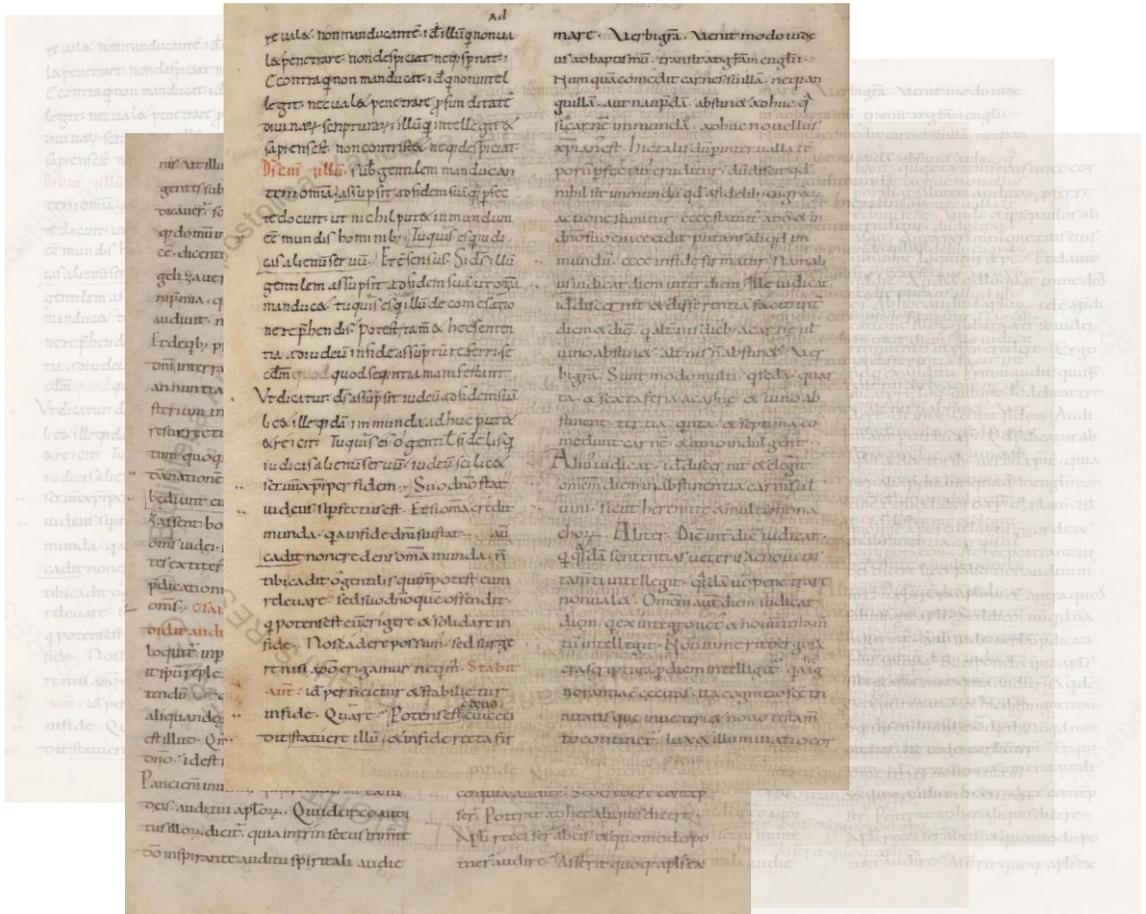
Scribe 2

Scribe 3



Handwriting Identification

Handwriting identification is the challenging problem of attributing handwritten texts to specific scribes



Scribe 1

Scribe 2

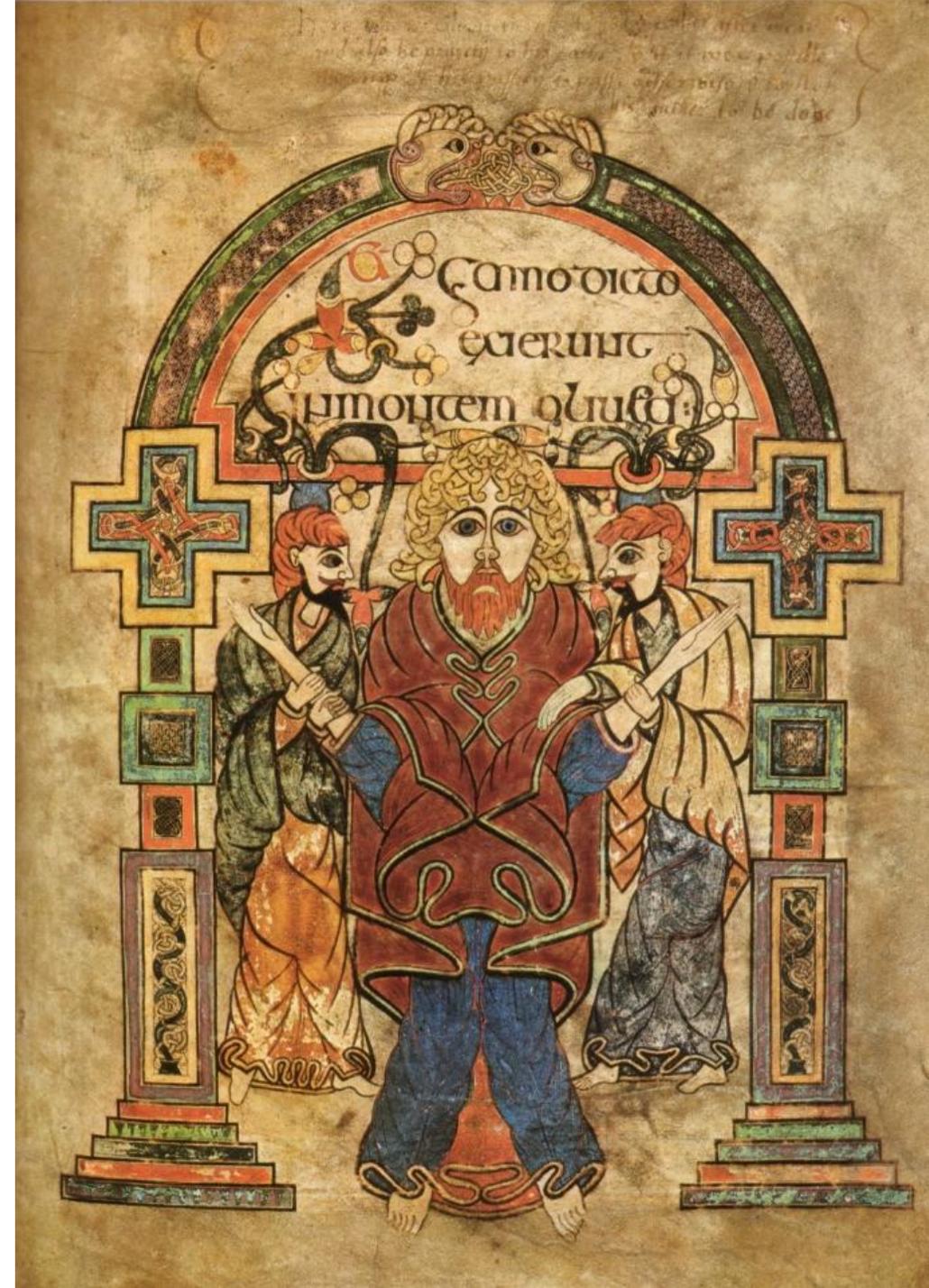
Scribe 3

A Classification Problem

Given a **collection of objects** and a set of **predefined classes**: assign objects to classes based on their features

In our context:

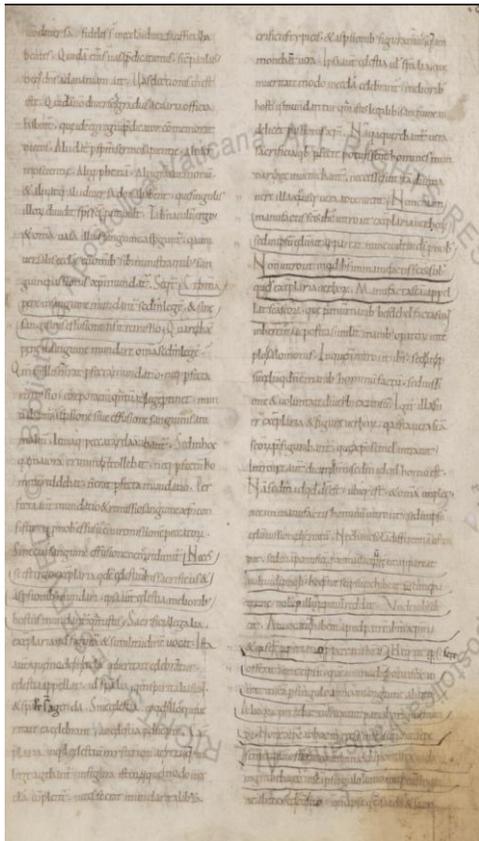
the **collection of objects** corresponds to **pages**, the **predefined classes** are the **scribes**



Machine Learning is the Solution

Stage 2: prediction

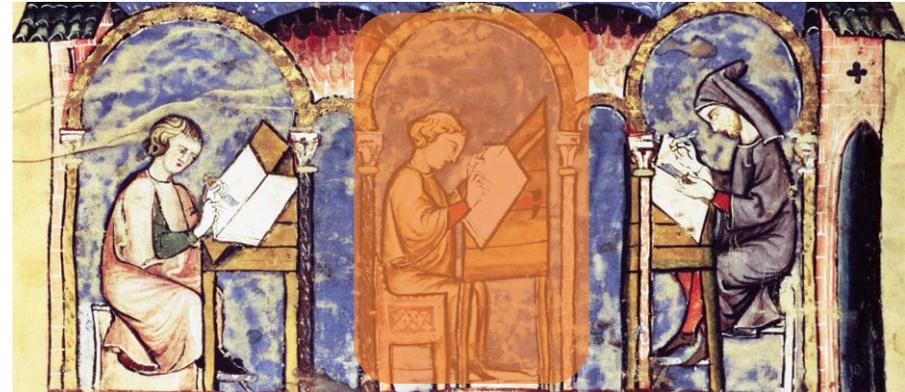
the system relies on these learned features to classify new pages that were not seen during the training stage



???

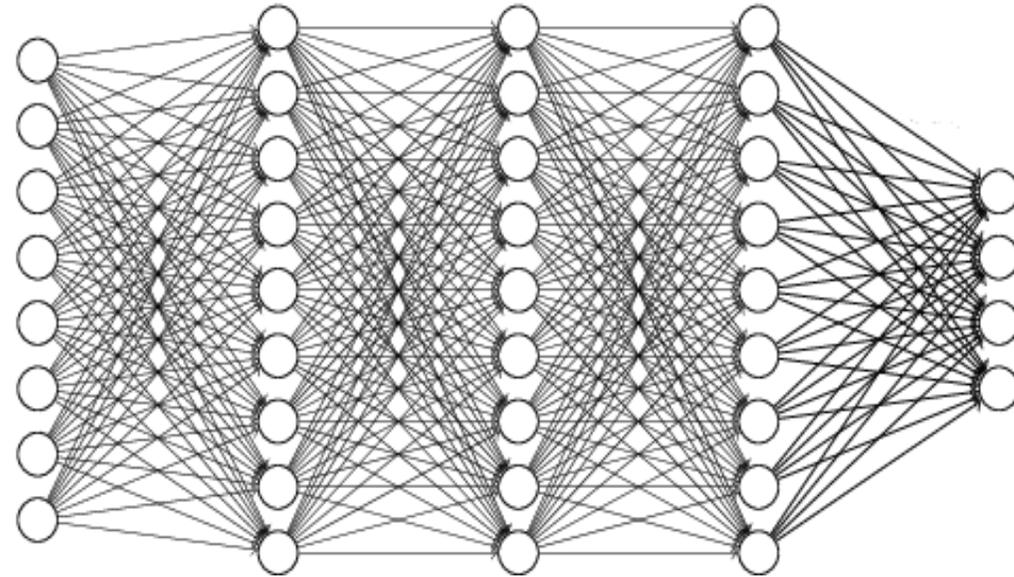
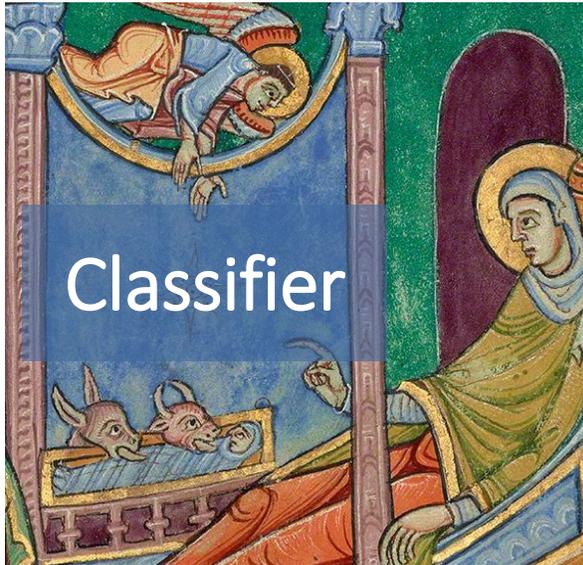


Scribe 2



Classifier: a Deep Neural Learning

We have used classifiers based on deep learning architectures (ResNet18*, V-Transformer**)

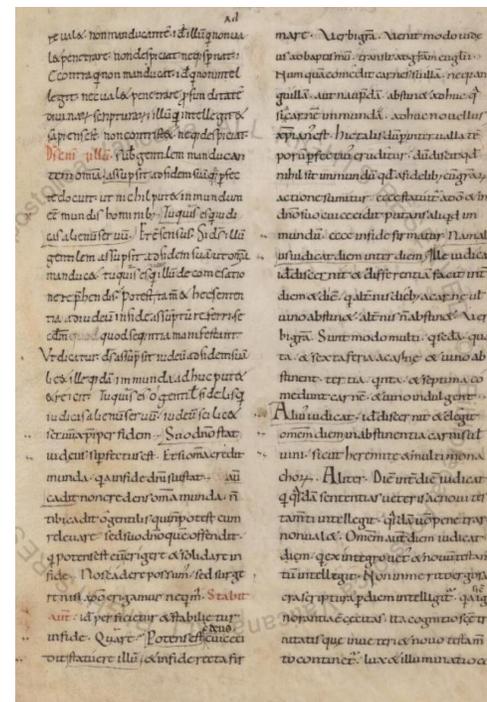


- * Ammirati et al. "Self-supervised learning for medieval handwriting identification: A case study from the Vatican Apostolic Library" Information Processing & Management 59 (3), 2022
- ** Liu et al. "Swin transformer: Hierarchical vision transformer using shifted windows" Proceedings of the IEEE/CVF international conference on computer vision. 2021

Case Study: Vat.lat.653

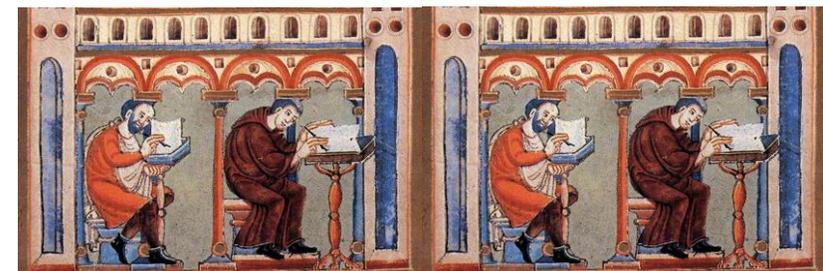
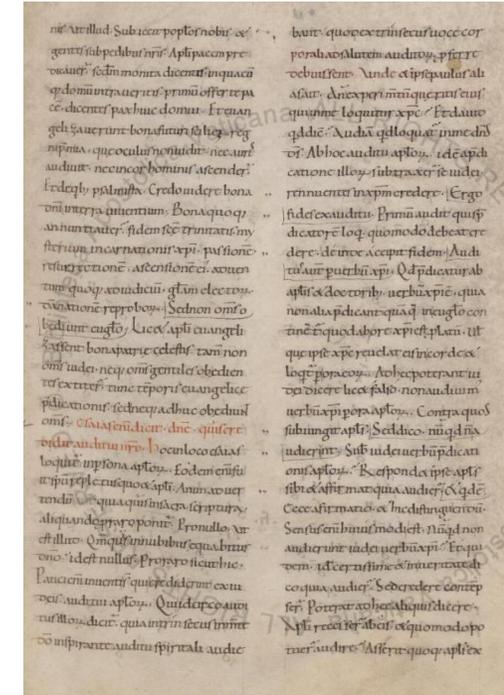
1279 px

- XI century, Subiaco
- 538 pages (269 folios)
- 4 scribal hands in 522 pages out of 538



902 px

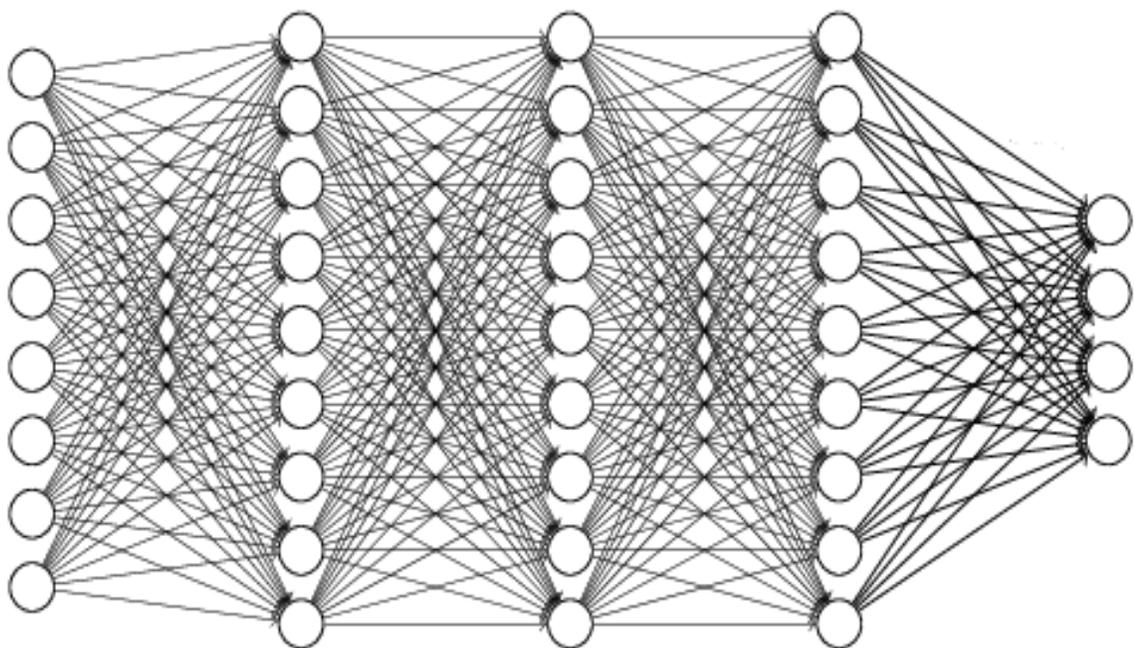
- scribe 1, 42 pages (fols. 1r-21v)
- scribe 2, 58 pages (fols. 237r-265v)
- scribe 3, 202 pages (fols. 22r-121v)
- scribe 4, 220 pages (fols. 122r-231v)

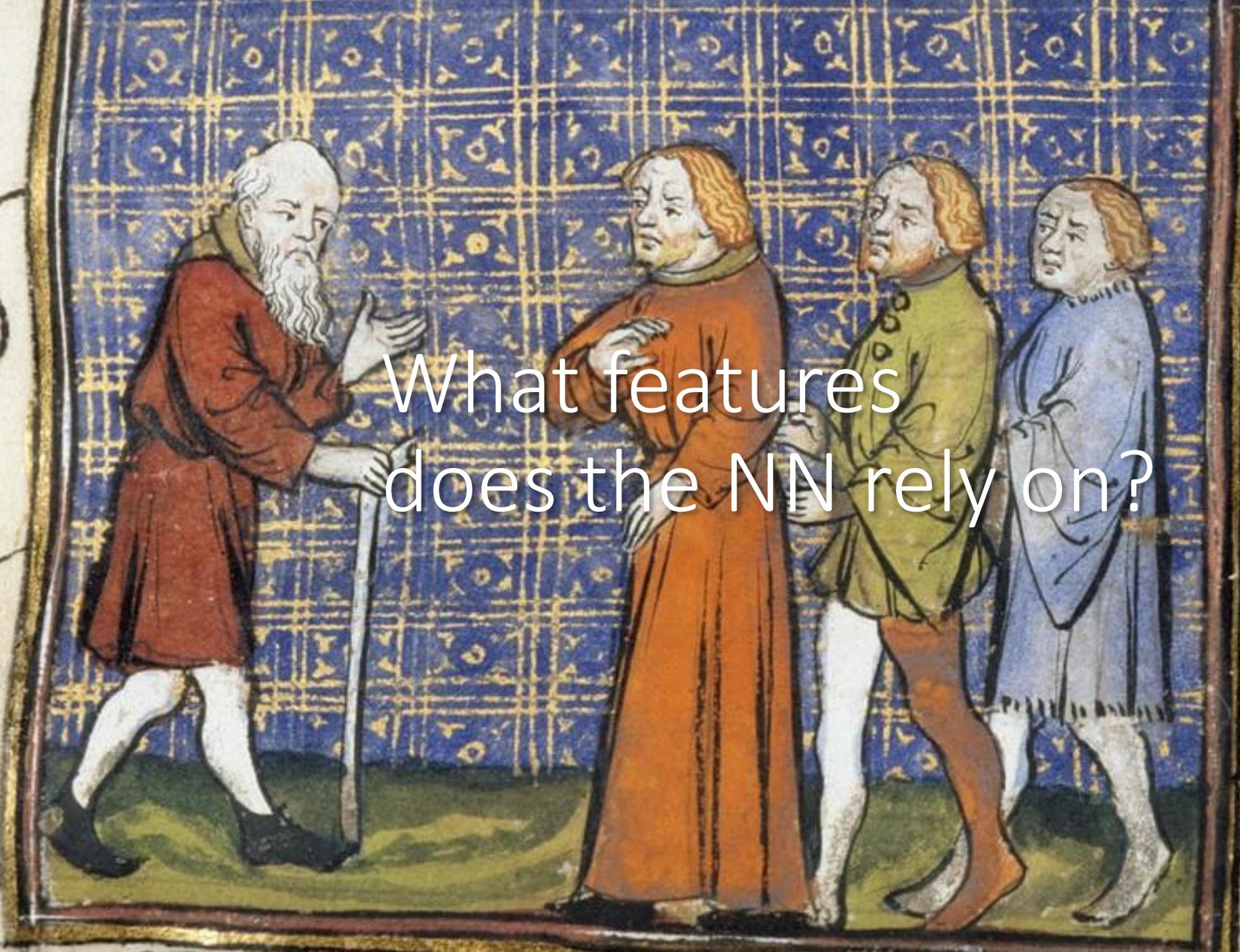


Classification Results (Accuracy)

ResNet18: 86%

V-Transformer: 91%





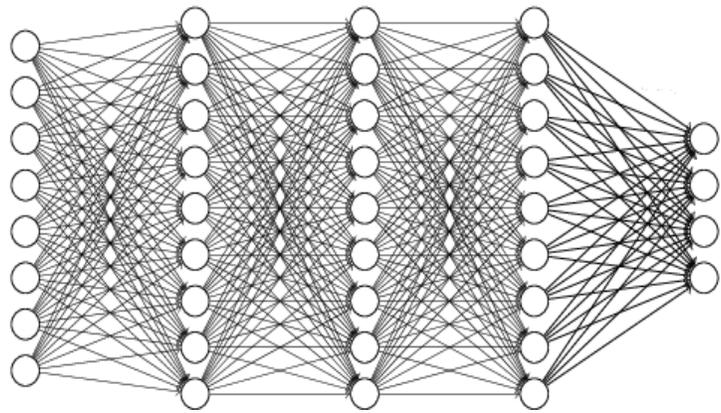
What features
does the NN rely on?

A medieval manuscript illustration depicting three figures standing under a decorative archway. The central figure is a man with a beard, wearing a blue cloak over a white tunic. He is flanked by two women: one on the left in a pinkish-red dress and one on the right in a blue dress. The archway is decorated with blue and red patterns. The background is a textured, brownish-green color.

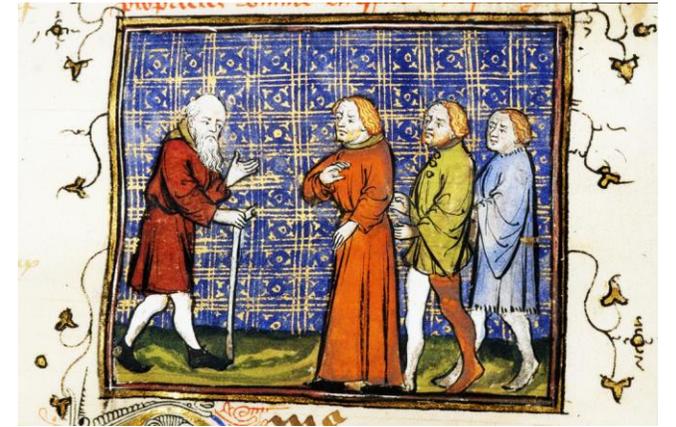
On which basis
can we trust the classifier?

The Black-box Problem

A neural network operates as a 'black-box':
we know the weights of the connections (millions)



Missal Box, 1490. New York Public Library



What are the features that
the neural network has
learned?
How is it attributing pages
to scribes?



Can we trust the classifier?

Our Approach to Generate Explanations

We have adapted LIME* to our analysis to highlight the relevant regions

Intuitively:

- we divide the image into square patches, each with a side length equal to the line height
- for each patch, we generate multiple perturbations and observe how the classifier's prediction changes

This allows LIME to infer the relative importance of each patch



*Local Interpretable Model-Agnostic Explanations

Ribeiro et al. "*Why Should I Trust You? Explaining the Predictions of Any Classifier*" KDD 2016

On-going Works, Collaborations, Questions

- Extend the study to other manuscripts.
- Can explainability build actual trust?
- Can we keep the computer scientists?
- Can we train the paleographers?
- Are DH competitive?



- Riccardo De Cesaris, PhD student in Computer Science, Roma Tre University (research project in DH)
- Elena De Luca, PhD in Paleography, Roma Tre University (summer and winter school in DH)
- Chiara Parlagreco, PhD in Paleography, Roma Tre University (Next Generation EU founded grant)
- Elena Pastorini, PhD in Digital Humanities, University of Bologna

EXPLET STORIE



Thank you!



Happy to take questions!