UMR IRISA

Activity Report 2018

Team INTUIDOC

Intuitive User Interaction for Documents

D6 – Media and Interactions

CentraleSupélec · cnrs · ens rennes · IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom · Inria · INSA Rennes · Université Bretagne Sud ubs · Université de Rennes 1

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2 Overall objectives

The Intuidoc team focuses its work on handwriting, gesture (2D and 3D) and documents under various aspects: analysis, recognition, composition, interpretation. We are also interested in human-document interaction and graphical/gestural man-document interaction. This research relates to the handwriting and the documents under different forms: manuscript, printed paper form, pen-based and touch-based interaction, graph, images, heterogeneous documents, etc.

The roadmap of the IntuiDoc team is on the frontier of several research axes: Pattern recognition, Machine-Learning, Artificial Intelligence, Human-Machine Interaction, Uses and Digital Learning. The aim is to explore new scientific challenges of the domain of the Human-Document Interaction with a specific focus on interactive, incremental and evolving learning based on the integration of the user in all the processes of analysis and decision making.

Today, four major emerging scientific axes are investigated with strong partnerships with national and international laboratories and companies:

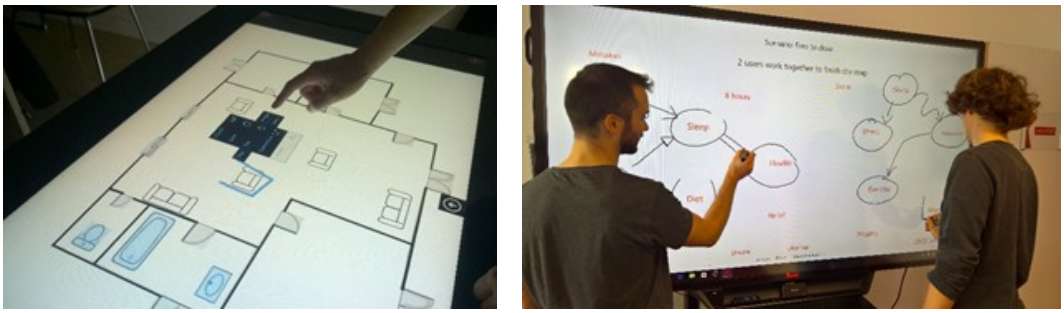
- "On-line" evolving cross-learning of 2D (touch and pen –based) and 3D gestures (Kinect and Leap Motion);
- "On-line" analysis of drawing, sketching and handwriting with pen-based tablet for digital learning (e-education);
- Interactive learning of document structure without ground-truth;
- Document collection analysis for big-data.

3 Scientific Foundations

3.1 On-line evolving cross-learning of 2D and 3D gestures.

3.1.1 2D evolving recognizer for gesture commands

With the increasing use of touch and pen-based sensitive screens, human-computer interactions are evolving. New interaction methods have been designed to take advantage of the new potential of interaction offered by these interfaces. Among them, a new concept has recently appeared: to associate commands to gestures. Those gesture commands enable users to execute various actions simply by drawing symbols. This new man-machine interaction can be used for on-line composition of complex documents such as electrical sketches or floor plan. In order to use such gesture commands, a recognition system is required. For users to easily memorize more than a dozen of gesture commands, it is important to enable gesture set customization. The classifier used to recognize drawn symbols must hence be customizable, able to learn from very few data, and evolving to learn new classes on-the-fly and improve during its use. The objective of this work is to obtain a gesture command system that cooperates as best as possible with the user, learning from its mistakes without soliciting the user too often. Gesture commands lead to a cross-learning situation where the user has to learn and memorize the gestures, and the classifier has to learn and recognize drawn gestures. We study the impact of different strategies to supervise the online training of an evolving recognizer for gesture commands, and how to optimize this cooperation between the user and the recognition system. In particular, we design an inner confidence measure to solicit the user when some data samples don't fit the classifier model, and that it will be very gainful to learn from it.



(a) (b)

Figure 1: Multi-Touch and Multi-User Interaction

3.1.2 Multi-touch gesture recognition

Due to the recent prevalence of multi-touch devices, multi-touch gesture recognition has gained a large interest in the last decade. Unlike mono-touch gesture recognition which tracks the movement of a single point of input, multi-touch gesture often tracks many points of contact in parallel as they appear, move and disappear. The recognition for multi-touch gestures is challenging because of the complex chronological relation between the fingers' trajectories. We are going to explore new methods for modelling the shape, relative temporal and motion information in multi-touch gesture by a model of graph and graph embedding approach. In our future work we aim at developing a strategy to detect the pattern of multi-touch gesture at runtime, to be able to address direct manipulation by command gesture.

3.1.3 Multiple users freely-drawn sketch recognition and 3D action gesture recognition

Another scientific challenge is also to address large multi-touch display that allows multiple users to simultaneously interact in the same context and work together. Indeed, many researches and commercial products propose tangible interfaces which support simultaneous participations of multiple users. This is a really new research topic to automatically recognize and interpret in real time the freely-drawn sketch of multiple users.

Finally, in this axe, we investigate the validity of transferring the expertise on hand-drawn symbol representation [6] to recognize 3D action gesture. This new research topic will be conducted in collaboration with MIMETIC project team of Inria. We base this proposition on the observation that patterns produced by a human motion, in particular 2D hand-drawn symbols and 3D actions, share several important properties. They are both governed by kinematic constraints that must be considered while modeling such human motions. We hypothesize that both recognition problems could be addressed in similar ways.

3.2 Artificial Intelligence for e-education

3.2.1 Handwriting analysis for digital learning at school

The scientific problem we tackle here is to quantitatively evaluate a cursive handwriting with respect to a reference model and recommendations of a teacher. In order to be able to teach

children how to write, we must be able to analyse their handwriting, to evaluate if the letters, words, sentences are correctly written, and to detail which aspects of the child handwriting do not correspond to the teacher models (corrective feedback). This problem is completely different from the classical task of character recognition, where the challenge is to determine to which class the data samples belongs.

Our objective is to be able to analyse, qualify and evaluate handwriting, with regards to reference models, and for multiple distinct aspects like: shape (for legibility), drawing direction and order (for ductus), speed and fluidity for instance. We use an analysis system based on an evolving fuzzy classifier. It allows to easily define reference models from few data samples to customize "on the fly" the writing exercises to the children. Then, the analysis system can be used to evaluate drawn gestures, regarding a specific feature set, and finally give a confidence score.

3.2.2 The ANR Joint laboratory (LabCom: Script&Labs) between IntuiDoc and Learn&Go

The axe of Artificial Intelligence for e-education has been launched with the IntuiScript project founded by the French government as part of innovative national projects (BPI-PIA2). IntuiScript targets towards offering an advanced digital writing experience at school by using tablets and tactile digital devices (with finger touch and stylus). This project is structured around the conception of a digital workbook to help teachers and children from three to seven years old during the handwriting learning process:

- it allows children to work in autonomy with an on-line and real time feedback;
- it proposes automatically pedagogical exercises that are adapted to children difficulties based on the automatic analysis of children writing;
- it provides a precise off-line analysis of children writing (i.e. order, direction, shape) to help teachers to understand children writing skills and difficulties.

This project was based on a user-centered design approach that includes several cycles of conception followed by experiments. Therefore, feedback of children and teachers related to these experiments have been used to improve the education scenario. More than 1,000 primary school students from Brittany have taken part to the experiments in the project.

This four years project was a real success. It resulted in the launch of the product "Kaligo" today distributed in schools by the company Learn & Go.

Figure 2: Handwriting analysis for digital learning

With the success of IntuiScript project, the IntuiDoc team and Learn&Go/Script&Go company created the "Script&Labs" LabCom to innovate on Digital Learning.

IntuiDoc team from IRISA laboratory has been a leader for more than 20 years in online analysis and recognition of writing and handwritten documents. Thanks to its expertise in Artificial Intelligence and more specifically in Machine Learning, it designs recognition and analysis engines allowing automated interpretation of online traces using pen-based tablets : handwriting, gestures, symbols, sketches, architecture plans... Learn&Go company, related to Script&Go, is specialized in developing digital solutions on tablets for mobility and e-education, aiming to improve learning through digital tools, from pre-schools to graduate higher education as well as in professional training.

The scientific principles of the joint laboratory belong to artificial intelligence (pattern recognition, Machine Learning) and man-agent interaction. Interpretation, adaptation and learning are the heart of its researches, aiming to conceive automated interpretation systems for children productions : writing, arithmetic operations, geometric figures. This scientific know-how form the foundation of new solutions in Digital Learning. leading to more independence and customisation for each student learning process.

The results of the joint laboratory will directly be used in innovating educational modules focusing in active learning, handwritten input, analysis and personalised help via immediate feedback on student production [11].

Three lines have been currently chosen :

- writing learning for young children
- learning numbers and first arithmetic calculations
- geometry learning by "generative drawing"

Beyond these three lines, LabCom Script&Labs helps working on "active and collaborative learning from secondary school to higher education" through e-Fran « Actif » et Cominlabs « e-Fil » projects.

The "ScriptAndLabs" joint laboratory is founded by ANR for three years (n° ANR-16-LVC2-0008-01)

3.2.3 "On-line" analysis of drawing for new learning strategies based on "generative drawing"

One of the key topics in this axe is how to encourage new learning strategy based on "generative drawing" using pen-based numerical devices. The goal is to improve the learning of students by considering "learning" as a generative activity. In this scope, the potential induced by pen-based tablet is really interesting. The goal is to investigate how we can automatically generate intelligent "corrective" or "predictive" feedbacks to a user during his drawing process: summarizing, mapping, drawing, sketching... We base this work on the visual grammar CD-CMG [9] (Context Driven Multi-set Grammar), to model the domain knowledge and interpret the hand-drawn sketches on the fly. We adapted this grammar to the Geometry domain to cover the concepts taught in middle-school (cf. Figure 3).

We explore this new research area in collaboration with researchers in psychology of the LP3C/LOUSTIC Laboratory of Rennes. To support this multi-disciplinary challenge, we have developed the new innovative four year national project "ACTIF" (BPI – e-FRAN) with the

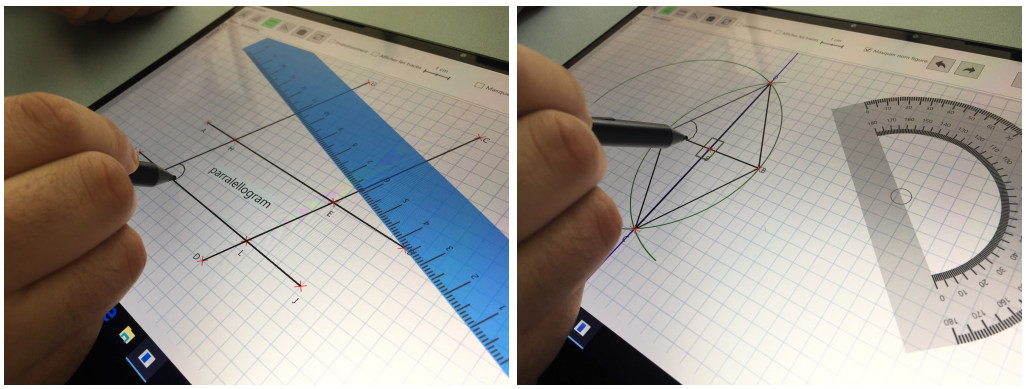


Figure 3: Pen-based and Gesture-based software for geometry learning.

support of the Brittany Region. The partners for this axe are LP3C and LOUSTIC laboratories, Learn&Go company, educational experts (ESPE) and Brittany region.

3.3 Interactive learning of document structure without ground-truth

3.3.1 Interactive Rule Inference

We work on the interactive learning of document structure, in the context of a thesis that has just ended. This work enables to combine statistical methods with syntactical approaches (grammars). Indeed, statistical methods are not able to convey two-dimension hierarchical structures that are common in document analysis. On the opposite, rule-based syntactical methods often require a fastidious manual step for the specification of the various organizations of the document physical layouts. The objective is to model the logical structure with rules and to learn the physical structure. This learning is based on databases of documents with ground-truth that are really costly to label. The current and future work aims at learning physical properties without ground-truth. The scientific context is to lean on large amount of documents and on generic document system analysis. We want to show that some knowledge can stand out from the repetition of physical structures, thanks to non-supervised learning methods. The challenge is to define strategies to make this learning possible thanks to an interaction with the user, which brings a semantic knowledge to the physical detected elements.

3.3.2 Combination Deep Learning / Syntactical

In collaboration with Richard Zanibbi from the Rochester Institute of Technology (RIT), Rochester, New York, USA, we will continue to work on interactive learning by combining deep learning technics, syntactical analysis and user interaction to introduce learning of segmentation. Deep learning methods like convolutional neural networks or recurrent neural networks have shown very interesting results in recognition by being able to make a common segmentation and recognition, with a good introduction of local context. But they are limited to a local context, which is interesting for the recognition of letters and words in a handwritten text line, but is not enough for a modeling and an understanding of a complex structure like the one we can find in a complex structured document. We propose to study the strong combination of deep learning and syntactical methods to build a document structure recognition system able to

deal with segmentation problems by learning them. The syntactical part models the structure and brings complex context to the deep learning recognition. The objective is to introduce in the architecture of the neural networks the large contextual information and to make the neural networks able to give not only a recognition but also information of localization of the recognized element. Indeed this localization information is important for the syntactical part to continue and explore different solutions in the global recognition of the document. To train the neural networks, we will have to focus also on a semi–automatic generation of datasets and ground truth, made by the grammatical description of the document, in combination with unsupervised clustering and a user interaction to generate ground truth with a minimum of manual work.

3.3.3 Spread Applications

These combinations could open large perspectives by simplifying the grammatical description as much as possible by learning the document structure, including regions of interest (segmentation), region types (classification) and their relationships (parsing/structure). Many applications could be studied on domains where it is important to combine deep learning and strong a priori knowledge. We will also make this combination able to deal with born digital documents (pdf, XML...) to address the huge quantities of documents, which need a real understanding for information extraction.

3.4 Document collection analysis for historical big-data

3.4.1 Handwritten Historical Registers

We start collaboration with Irccyn - University of Nantes on the layout recognition of registers of the Théâtre-Italien from the 18th century. The University of Nantes is a partner of the ANR CIREFI and will work with the DMOS-PI method, proposed by IntuiDoc, to build a document structure recognition system for these handwritten registers, which will drive handwritten text recognizers, to make a complete information retrieval system.

3.4.2 Strategies for Sequential Collection

The DMOS-PI method proposes a framework for the analysis of collections of documents. It enables to share information from the collection between the pages, thanks to an iterative mechanism of analysis. This mechanism also makes it possible to integrate an asynchronous interaction between automatic analysis and human operators. We propose to work on modeling strategies of analysis for the analysis of collections of documents. The strategies could sequence the various iterative treatments of documents pages, the global treatments and the interactions. The interest is to exploit as much knowledge as possible on the collection in order to make the extraction of information in each analyzed pages more reliable, and to make the understanding between the various data at the collection level easier. In this context, the ANR HBDEX project has been selected. It is led by the PSE "Paris School of Economics" ("Ecole d'économie de Paris"), with the LITIS lab in Rouen and the CAMS-EHESS. This project focuses on the extraction of historical big-data for digital humanities, applied to financial data. The objective is to analyse masses of tabular data: daily listing on the Stock Exchange from the 19th and 20th centuries. The analysis will be based on the redundancy between the successive days of listing and the consistency between the global sequences of data. This modeling will enable a fast

adaptation to other kinds of historical tabular data that only exist on a paper form (economic, demographic, meteorological), but that is necessary to constitute historical big-data databases. This opens a large possibility of applications on documents found in all statistical institutes.

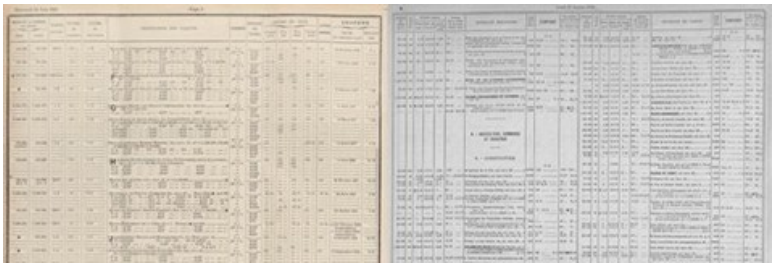


Figure 4: Examples of daily listing on the Paris Stock Exchange

3.4.3 Adaptive Document Layout Analysis

We propose to integrate the interactive document structure learning without ground truth and the collection modeling to generate an adaptive document layout analysis system where a user, with few interactions, could make the recognition system learn new layouts to adapt itself and improve the global recognition quality. We will build this adaptive document layout system on the European project EURHISFIRM (InfraDev). EURHISFIRM designs a world-class research infrastructure (RI) to connect, collect, collate, align, and share detailed, reliable, and standardized long-term financial, governance, and geographical data on European companies. This project is leaded by the PSE "Paris School of Economics" ("Ecole d'économie de Paris"), with seven partners working on quantitative economics and finance, economic and social history, and the LITIS Lab in Rouen working with us on document images analysis. We will work on a system to extract high-quality data from historical serial printed sources, to address three issues: (i) lowering the costs of data extraction from the same source; (ii) lowering the cost of adaptation of the system from one source to the other; (iii) developing effective data validation process. Interactions between the system and experts on the sources lay at the heart of the conception.

4 Scientific achievements

4.1 Text-line localisation in ancient documents

Participants: Camille Guerry, Bertrand Coüasnon, Aurélie Lemaitre.

This work focuses on text-line localisation, in handwritten documents, in interaction with tabular structure. The figure 5 shows difficulties to differentiate the cases (a) and (b) without contextual information. CBAD competition ([DKF+17] ICDAR 2017) proposes a challenging data-set with documents containing heterogeneous and complex structures.

[DKF+17] M. Diem, F. Kleber, S. Fiel, B. Gatos, T. Grüning, "cBAD: ICDAR2017 Competition on Baseline Detection", *in: 2017 14th IAPR International Conference on Document Analysis and Recognition*, p. 1355–1360, 2017.

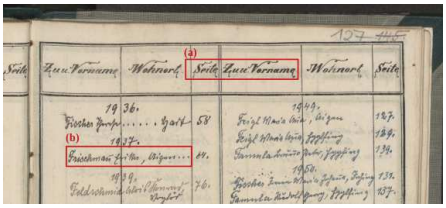


Figure 5: Ambiguities generated by the interaction between text and tabular structure : (a) two different lines are very close from each other, (b) a single line crosses the tabular structure.

In this context, we propose a method which improves baselines localization in ancient documents containing tabular structures thanks a combination of deep-learnig and syntactic approaches. The aim of the deep-learnig part is to produce contextual information and the aim of the syntactic part is to interpret those information in a structural context. We use the architecture of neural network proposed by Oliveria et al. [AOSK18] (dhSegment) and train a model in order to predict different contextual elements (see figure 6). A grammatical description written in EPF is then used to combine all those information.

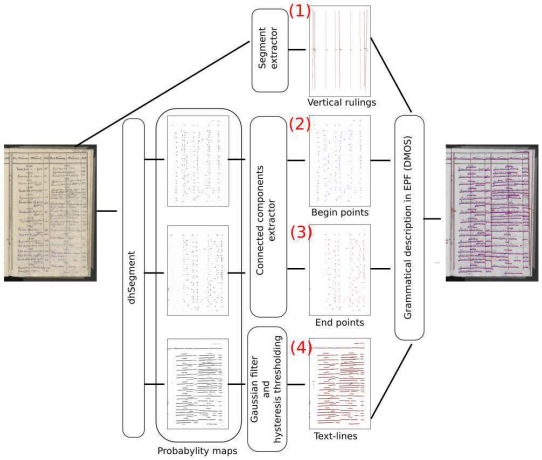


Figure 6: Overview of the system

Method	P-val	R-val	F-val
IRISA	0.692	0.772	0.730
UPVLC	0.833	0.606	0.702
BYU	0.773	0.820	0.796
DMRZ	0.854	0.863	0.859
dhSegment	0.826	0.924	0.872
Our Combination	**0.858**	**0.935**	**0.895**

Table 1: cBAD Competition on baseline detection [DKF+17] (Test set -Complex Track)

In table 1, we compare our results with state-of-the-art methods on cBAD data-set [DKF+17].

[AOSK18] S. Ares Oliveira, B. Seguin, F. Kaplan, "dhSegment: A generic deep-learning approach for document segmentation", *in: Frontiers in Handwriting Recognition (ICFHR), 2018 16th International Conference on*, IEEE, p. 7–12, 2018.

4.2 Interactive combination of deep learning and syntactical methods for contextual segmentation and structure learning in document recognition

Participants: Kwon-Young Choi, Bertrand Coüasnon, Yann Ricquebourg.

This work is done in the context of a collaboration with Richard Zanibbi from the Rochester Institute of Technology (see 6.4.1). We propose a new small and fast deep learning detector adapted to the detection of music symbols in dense and noisy historical music scores. The use of a neural network detector allows us to merge the segmentation and classification task which performs better with broken and touching symbols 4.2.

(a) Broken symbol (b) Touching symbols

Figure 7: Examples of segmentation problems

The particularity of this detector is the seamless integration of a Spatial Transformer layer that allows to also use the localization information as an attention mechanism. Using this architecture, we obtained a mAP of 94.8% with an IoU threshold of 0.75. We compare with state-of-the-art deep learning object detectors like Faster R-CNN, R-FCN and SSD producing respectively 98.3%, 98.7% and 97.8% mAP with an IoU threshold of 0.75. More work is currently being done to modify this architecture to do multi-objects detection.

In a collaborative work with Alexander Pacha from Institute for Software Technology and Interactive Systems in Vienna Austria, we also applied these detectors to the newly produced MUSCIMA++ dataset that contains symbol level annotation of 140 pages of handwritten music scores. Preliminary results shows that the best performing model is producing a mean average precision of 80% with a vocabulary of 71 very diverse classes of music symbols. These results were presented in [24].

The seamless integration of the Spatial Transformer network also allows for new unsupervised training of the detection task by using Generative Adversarial training scheme.Another unsupervised method is also currently being explored by using synthetic data to train a supervised neural network detector like the Faster R-CNN and ongoing work was presented at ISMIR 2018 [18]. The extraction of synthetic data is done by using the music typesetting software MuseScore and we plan to make it a publicly accessible dataset.

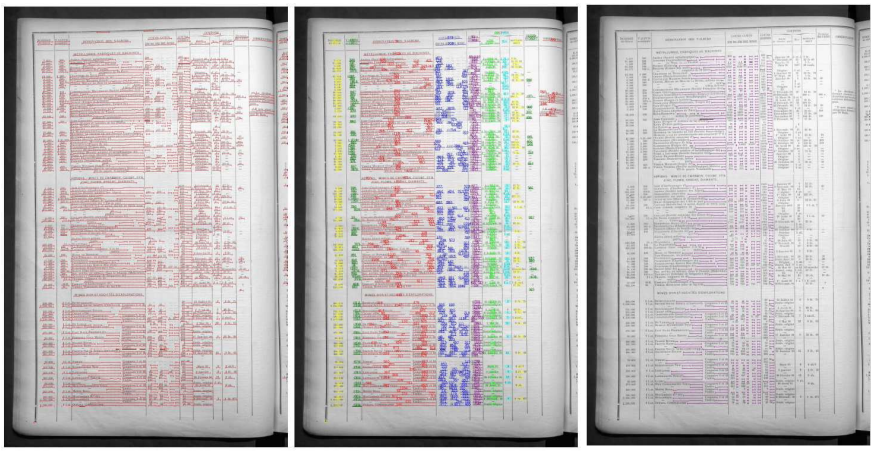
Finally, we integrate this detection model into the DMOS-P method using a music grammar. This grammar allows us to use the context of the music score to reduce the possible area of detection. After running our detector on the specific areas, we reuse the detection results in the grammar in order to complete the recognition of the music score.

4.3 Historical big-data : modelization of strategies to analyse collections of documents

Participants: Camille Guerry, Bertrand Coüasnon, Aurélie Lemaitre, Jean Camillerapp.

In the context of the ANR project HBDEX (see 6.2.4), we work on the recognition of tabular structures in daily listing of the Strock Exchange from the 19th and 20th centuries. The aim of the HBDEX project is to develop a recognition strategy that takes into account the consistency between the global sequences of data (see 6.2.4).

In this context, we propose a first prototype which is able to extract text-lines and recognize which column they belong to. Text-lines are extracted thanks a fully convolutional network that follows the architecture proposed by Oliveria et. al. [AOSK18]. Then, we use a grammatical description of the tabular structure written in EPF in order to associate each text-line to a column.(figure 8 (b)).



(a) (b) (c)

Figure 8: (a) Line extracted thanks dhSegment - (b) Column recognition - (c) Dotted lines extraction

We produce an output file, containing all the extracted text-lines and for each text-line : a polygonal chains representing the baseline; the identifier of the column containing the text-line; a Boolean that indicates if the baseline correspond to a column title or not.

This first prototype will be used by the LITIS lab in order to generate data to learn a first model for text recognition.

We also begin the elaboration of a grammatical description able to recognize rows. Each row corresponds to financial security. The strategy is to extend text-lines which are close together and in the same axis. In order to be able to extend text-lines even if the line is interrupted by dotted points, we use the dotted line extractor (see figure 8 (c)).

4.4 Online 3D actions recognition by analyzing the trajectories of human's skeleton

Participants: Said-Yacine Boulahia, Eric Anquetil, Richard Kulpa, Franck Multon.

This research work is part of a thesis conducted in collaboration with MIMETIC project team of Inria. The main goal of this thesis is to investigate the validity of transferring the expertise on hand-drawn symbol representation to recognize 3D gestures. We base this proposition

[AOSK18] S. Ares Oliveira, B. Seguin, F. Kaplan, "dhSegment: A generic deep-learning approach for document segmentation", *in: Frontiers in Handwriting Recognition (ICFHR), 2018 16th International Conference on*, IEEE, p. 7–12, 2018.

on the observation that patterns produced by a human motion, in particular 2D hand-drawn symbols and 3D gestures, share several important properties. In this work we particularly consider the modelling and recognition of 3D dynamic hand gestures.

Being able to interactively detect and recognize 3D actions based on skeleton data, in unsegmented streams, has become an important computer vision topic. It raises three scientific problems in relation with variability. The first one is the temporal variability that occurs when subjects perform gestures with different speeds. The second one is the inter-class spatial variability, which refers to disparities between the displacement amounts induced by different classes (i.e. long vs. short movements). The last one is the intra-class spatial variability caused by differences in style and gesture amplitude.

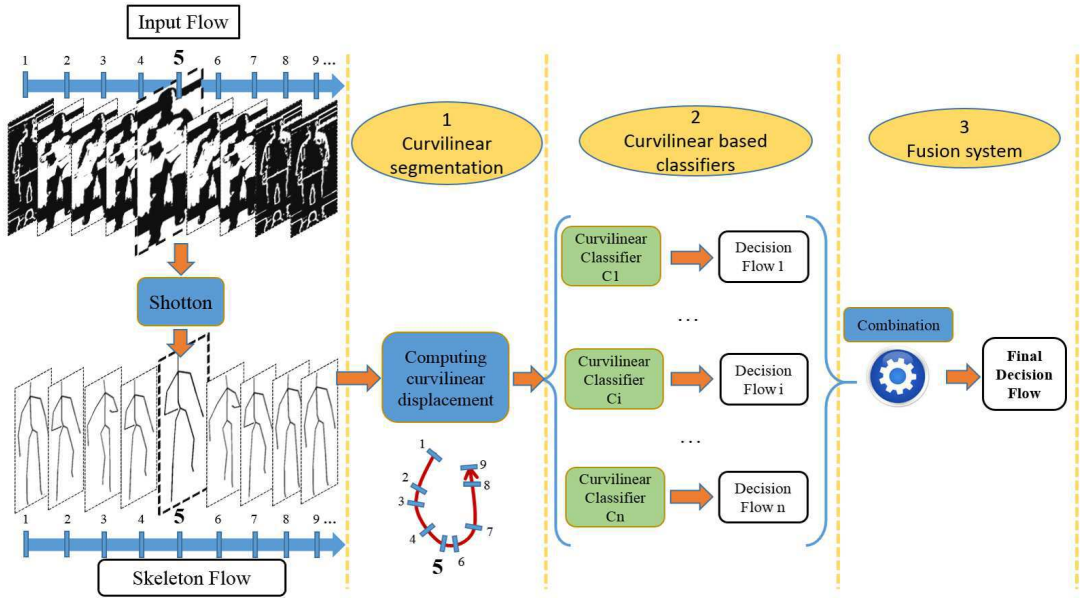


Figure 9: Illustration of the major steps constituting our dynamic hand gesture recognition approach

We design an original approach that better considers these three issues (cf. figure 9). To address temporal variability we introduce the notion of curvilinear segmentation. It consists in extracting features, not on temporally-based sliding windows, but on trajectory segments for which the cumulated displacement equals a class-based amount. Second, to tackle inter-class spatial variability, we define several competing classifiers with their dedicated curvilinear windows. Last, we address intra-class spatial variability by designing a fusion system that takes the decisions and confidence scores of every competing classifier into account.

Extensive experiments on four challenging skeleton-based datasets demonstrate the relevance of the proposed approach for action recognition and online action detection [17, 13].

Yacine Boulahia defended his PhD on october 2018 ([12])

4.5 Active learning with pen-based tablet

Participants: Sébastien Thomas, Mickaël Renault, Eric Anquetil, Nathalie Girard

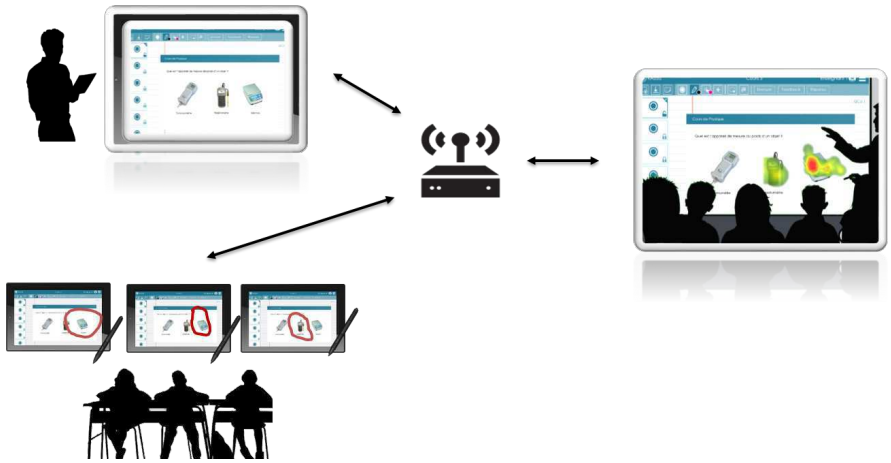


Figure 10: Handwritten graphical quizzes composition

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The eFil Cominlabs project (see 6.2.3) is based on CAMIA/KASSIS which is a new digital learning environment (workbook) for active learning with pen-based tablet. The goal of the eFIL Project is to optimize and evaluate this digital learning environment in classroom settings during lectures (Optimizing with user-centered design). Traces will be collected and analyzed both to explore learning dynamics in classroom, and to provide a dashboard allowing instructors to monitor their activities during lectures as well as in-between sessions. The goal is to explore and analyze traces to monitor learning activities in classroom with Educational Data Mining and Learning Analytics.

The KASSIS software has been extended to monitor users activity, collecting information about the way people use it. To implement this extension we provide a client-server solution. It is important to mention that, we don't have to collect what people are writing or drawing but only their overall activity (which page they are looking at, the fact they wrote a note on some page...) All these on-line traces will be analyzed by LS2N laboratory to design a dashboard. The goal of this dashboard is to monitor their proceedings both in real time during the activity (for course and students' activity steering) or after (for reflective analysis of pedagogical strategy, student progress measurement, course evolution).

The KASSIS solution offers the possibility to compose handwritten advanced graphical quizzes for teachers: questions can be expressed on-the fly, by sketching or drawing directly on the tablet display and responses are also handwritten by students. All the graphical responses are collected in real time to produce immediate feedback for students and teacher. Along with these trace data, we added the ability for the teacher to indicate the correct answer to quizzes in the software, which enables to display visual correction feedback to the students and to compute quizz statistics in the dashboard (see figure 10).

The KASSIS solution has been also extended with the ability to make a real time aggregation, analysis and restitution of the graphical responses of the student by two ways:

- for hand-drawn responses as emphasize, surround...: we aggregate the graphical responses in the form of a heat map in which areas containing a majority of answers are highlighted.

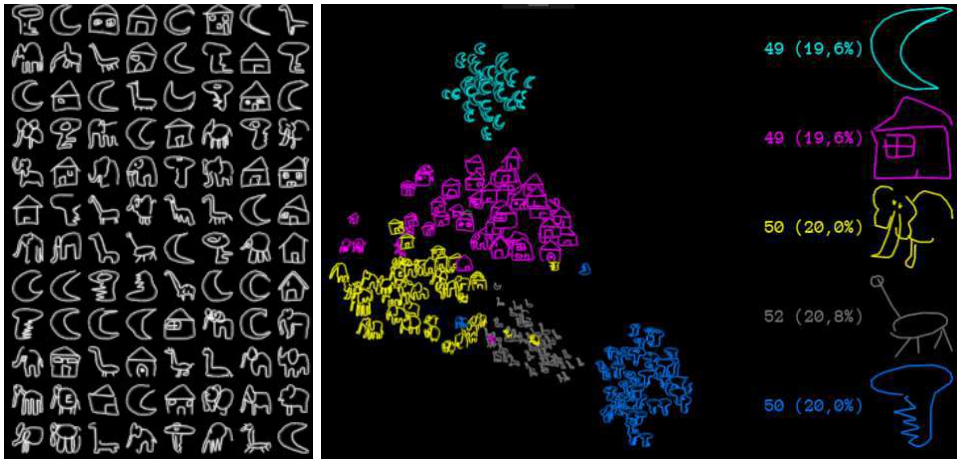

Figure 11: raw data and Answer clustering

- for hand-drawn responses as sketches, handwritten formula...: in conjunction with the eFran Project ACTIF (see section 4.6) a prototype has been realised to analyze the student's answers which are freehand graphical drawing. Students answers are automatically clustered by similarity in a 3D display, allowing the teacher to quickly see the different kind of answers in a large group (see figure 11). This new 3D graphical feedback will soon be integrated in KASSIS software to be evaluated in classroom by LP3C laboratory.

4.6 Automatic clustering of handwriting gestures

Participants: Mohammed Hindawi, Eric Anquetil, Nathalie Girard, Sébastien Thomas

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This work is a part of e-FRAN ACTIF project (see 6.2.2 Learning and Collaboration with digital Tablets, Interactions and Feedback), which is an educational project aiming at improving the quality of teaching, by enhancing and reinforcing the connection between teacher and students, and among the students themselves. ACTIF project concern middle school.But, this work is also linked with the Labex project e-Fil (see 6.2.3) for active learning in higher education for face-to-face lectures.

Today, new digital devices open many opportunities for innovation in the field of learning. The range of digital devices is very large and still largely unexploited: digital tablet, pen-based computer, electronic pen, notebook, interactive screen, multi-touch table, ... All these digital tools induce potential for new uses that are yet to be imagined: digital handwritten annotation or drawing, multi-user and multi-media interaction, interaction with peers, collaborative learning, real-time feedback...

This work focuses on one functionality: handwritten advanced graphical quizzes composition for teachers:

- Questions can be expressed on-the fly, by sketching or drawing directly on the tablet display (going beyond rigid and planned interaction based quizzes or push button);

- Responses are also handwritten by students. We have to collect all the graphical responses in real time to produce an analysis and a restitution of the collected responses to produce immediate feedback for students and teacher.

The problematic of this work is to cluster the graphical responses (hereafter sketches) of students; and to give a compact and real-time representation that is exploitable by the teacher and the students.

In order to deal with the presented problematic we propose the following chain of processing steps (Figure 4.6):

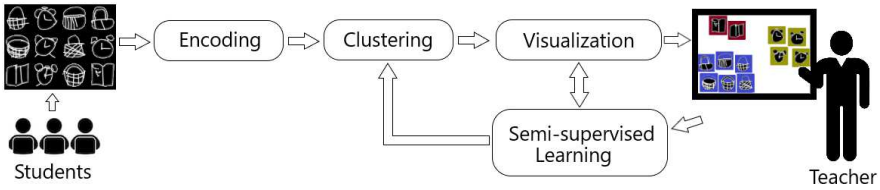


Figure 12: Proposed Sketch Clustering System

1. **Encoding the Sketches (Features Extraction):** The first and trivial step in the chain is the re-representation of the sketches in the domain of data mining (i.e. numerical representation). The so-called "features extraction" process is well known in the domain of handwriting recognition. Generally, this is done by calculating certain domain-specific measures that best discriminate data according to desired classes. We use the HBF49 feature set ([6]) extended by ([11]) where new features were added in order to improve the description. The total number of "shape-describing" features that we used was 70 features.

2. **Unsupervised Learning of the resulting numerical data (Data Clustering):** The second step in the chain is clustering the sketches into groups (clusters) in order to apply some statistical measures and thus making the students' responses (sketches) more communicative to the teacher. We use Fuzzy C-Means clustering and explore different strategies such as dimensionality reduction and/or Co-clustering. Note that this step is done without any intervention of the teacher (no background information, unsupervised learning).

3. **Interactive Visualization of the data results of clustering (Data Visualization):** The next step is to visualize the data to the teacher. We present an effective and interactive visualization interface that shows the results considering two parts, the first one is visualizing the data based on its natural structure; this implies using some dimensionality reduction techniques in order to pass from the original representation domain (all features) to a 2D (or 3D) domain that can be viewed on the screen. The second part is projecting the clustering results over the data. Once done, the teacher has a first result of his/her question with some preliminary statistics.

4. **Semi-Supervised Learning (Constrained Clustering):** This step is optional but we believe that it would be of grand benefit for the teacher. In fact, based on the first results shown to the teacher, (s)he might want a specific clustering based on some criteria and/or additional information, this led us to a new scientific direction which is the semi-supervised clustering, which utilizes some background knowledge in clustering process.

Note that this background knowledge might be of various forms (deciding –à priori– the number of clusters, re-clustering using some constraints (labels subset), etc.).

4.7 Real-time interpretation of geometric shapes for digital learning

Participants: Omar Krichen, Eric Anquetil, Nathalie Girard, Mickaël Renault, Simon Corbillé.

Keywords: Online recognition, Hand-draw stroke analysis, Digital learning, gestures and stylus interaction.

This work is in the context of e-FRAN ACTIF projects (see 6.2.2, which aims to use pen-based tablets in an educational context to foster active and collaborative learning in French middle-schools. The partners are LP3C and LOUSTIC laboratories, Learn&Go company, educational experts (ESPE) and Brittany region. The goal is to allow students to draw geometric shapes on the fly (see figure 13), given a teacher's instruction. The system has to recognize on the fly the user's drawings in order to produce real time visual, corrective and guidance feed-backs.

4.7.1 The online interpretation of hand-drawn sketches based on a hierarchical bi-dimensional grammar

We base our work on the visual grammar CD-CMG [9] (Context Driven Multi-set Grammar), to model the domain knowledge and interpret the hand-drawn sketches on the fly. We adapted this grammar to the Geometry domain to cover the concepts taught in middle-school. Given the application field is complex, the sketches analysis process generates combinatorial problems. To tackle this issue, we extend the definition and the parsing of bi-dimensional grammars by formalizing a hierarchy between production rules. Therefore, we propose alternative exploration strategies and reduce the search space of applicable production rules at any given level of the analysis.

The hierarchy is present through two aspects: the first one being **production rules hierarchization**, by the definition of rules layers corresponding to the different layers of interpretation of the application domain. In the Geometry context, we distinguish between four layers: the first one is related to the recognition of basic shapes. The second one is related to the connection rules (such as segments or arcs intersections). The third one is related to polygons creation and the fourth layer corresponds to the mathematical analysis of those polygons (triangles, quadrilaterals). From a grammatical point of view, we define an operator called *RuleLayer* [20] that specifies, for each production, the corresponding interpretation layer. This means that at a particular level of the analysis tree, the parser will only trigger productions belonging to the same hierarchy level, therefore reducing the space of applicable rules and reducing the analysis complexity.

The second aspect is the **context hierarchization**, which forces the parser to choose the first valid structural context to reduce a production rules instead of having an exhaustive analysis of all the possible hypothesis, made possible by the definition of a new operator called *FirstContext* [21]. This constitutes a trade-off between precision and analysis complexity. The system has been tested with different drawing scenarios of geometric figures sketching. It reached interesting real-time performance, without loosing the generic aspect of the approach.

These works have been the object of two research papers, presented in the International Conference on Pattern Recognition and Artificial Intelligence (ICPRAI) [21], and the International Conference on Frontiers of Handwriting Recognition (ICFHR) [20]. The early works have also been presented in poster format on the first e-FRAN seminar [25]. Moreover, to operate all the experimentation in middle-schools a prototype(named IntuiGeo) have been completely design.

4.7.2 "IntuiGeo": design and development of the Prototype

"IntuiGeo" is a tool for geometry learning support on stylus tablets. The idea here is to perform a geometry exercise on a digital medium by simulating the traditional pen and paper figure sketching. We propose an intuitive interaction where the virtual tools, like the ruler, are manipulated with the fingers while the geometric figures are drawn with the pen. Thus, the learning process is similar to the one used on traditional method. The student is guided by real-time feedbacks. Figure 13 presents the prototype interface. We follow the paradigm of user-centred design process, where the teachers and the children experimenting "IntuiGeo" are included in the design loop. In the early stages of our work, the approach was validated by pedagogical experts from the Academy of Rennes.

The first user tests have been realized on the first prototype by our partners from LP3C and LOUSTIC, with 12 volunteer pupils from a middle-school in Brittany. These initial tests showed the interest and satisfaction of pupils and teachers, despite some difficulties encountered due to some imperfections of the first prototype.

We have extended the first prototype with many features to tackle the encountered issues. Now, "IntuiGeo" disposes of four virtual tools: a ruler, a protractor, a compass and a set square. These tools can make a measure or draw a specific figure. For example, the set square can be used to verify if two segments are orthogonal or to make a perpendicular. Each tool have a helper for anchoring it on interest points and a helper for drawing smooth strokes like a straight line with the ruler. We also have an edition mode where we can modify an angle, a segment length, or a figure by freely moving its extremities.

Our colleagues of Loustic laboratory will realize several tests of IntuiGeo in pilot middle-schools in Brittany. About 60 students will participate and the tests will start in December 2018. The results of these experimentations will allow to study the impact of this type of application on the learning process compared to traditional approach. Furthermore, demonstrations of the software have been performed at the LabCom launching day at Rennes the 18 October, the IHM conference at Brest the 24 October [19], and the Loustic study day at Rennes the 15 November.

4.8 Mathematical expression recognition and analysis

Participants: Arnaud Lods, Eric Anquetil, Sébastien Macé from Learn&Go company.

This part sum up the work done for the first thesis' year of A. Lods that began on January 2018 on the subject of **On-line analysis of handwritten arithmetic operation on digital tablet: Design of an innovative educational solution to improve learning arithmetic calculations in elementary school**. This thesis is carried out in collaboration with the LabCom "Script&Labs" (see section 6.2.1) and is financed as a CIFRE by the ANR n°ANR-16-LVC2-0008-01.

The objective of the thesis is to produce a pen-based tablet application to provide children

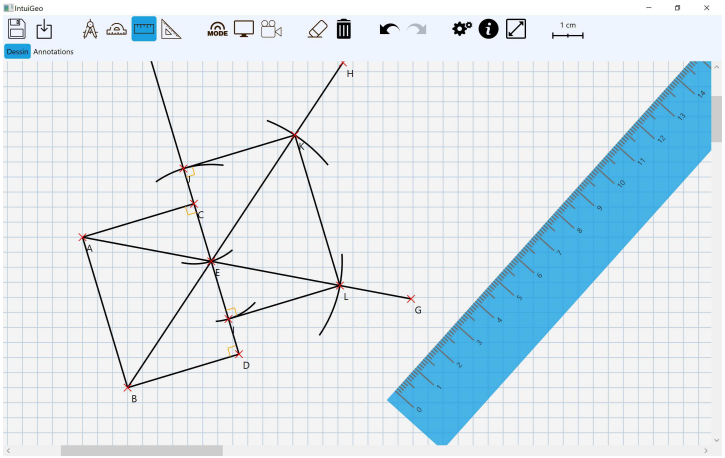


Figure 13: IntuiGeo IHM

in elementary school with an application to practice solving arithmetic operation (addition, subtraction...). Given a mathematical problem proposed by a teacher, the child is expected to solve this problem the same way he would using a pen on a paper. The system then analyzes the student handwritten input and analyse it knowing the expected solution. If errors are detected because of miscalculation, algorithm misunderstanding, omission (if he forgot to carry over in addition or subtraction) or misplacement, the system guides the student to fix his mistakes.

To tackle this problem, we first develop a system for the recognition of mathematical expression for experimental validation. We use the CROHME datasets [MZGVG16] composed of thousands of mathematical expression. Each expression is represented by a sequence of strokes registered by an user. The different tasks of both the recognition and analysis of these expressions are : the *strokes segmentation* into independant symbols, the *classification of these symbols* and the *classification of the relation* between pair of symbols to build the mathematical expression.

We intend to solve this problematic by building as a first step a stroke graph with symbolic links. The idea is to create link between strokes through extracted characteristics that can approximate as much as possible the human vision. This way we would be able to explain **why** such links are created, and thus ease the analysis process. We use the knowledge from the previous work of Adrien Delaye [Del11] on fuzzy logic. We try to learn different type of relations that can be found in mathematical expressions that corresponds to human-based vision (supscript, subscript ...) to link pair of strokes. These features extracted are useful in the system for later classification, mostly for the task of *relations clasification*. Moreover by linking strokes with logical links we should be able to reduce by a large margin the number of links created at the first step of the system, thus reducing both the time needed to compute the tasks and the probabilities of wrong classification as there would be less poor links.

The table 4.8 and Figure 14 presents some results obtained with such graphs on CROHME

[MZGVG16] H. Mouchere, R. Zanibbi, U. Garain, C. Viard-Gaudin, "Advancing the state of the art for handwritten math recognition: the crohme competitions, 2011–2014", *International Journal on Document Analysis and Recognition (IJDAR) 19*, 2, 2016, p. 173–189.

[Del11] A. Delaye, *Méta-modèles de positionnement spatial pour la reconnaissance de tracés manuscrits*, PdD Thesis, INSA de Rennes, 2011.

CROHME2014	Expression	Recall	Precision	F-score
Complete	1.00	100.00	9.15	16.76
Line of Sight	0.99	99.89	29.11	45.08
Fuzzy	0.94	99.61	47.74	64.54
6-NN	0.85	98.18	32.11	48.39
Time Series	0.37	85.43	91.66	88.43
2-NN	0.27	78.73	64.21	70.74

Table 2: Link generation in our fuzzy graph compared to other standard graph. *Expression* represents the % of mathematical expressions in which no links are missing. Both recall (% of links from ground-truth preserved) and precision (% of useless links) are presented.

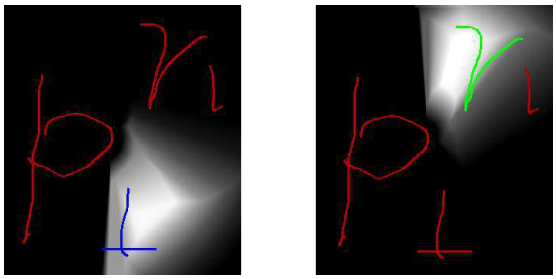


Figure 14: Fuzzy landscape learned for Sub-script and Super-script mathematical relationship

datasets.

Preliminary work has been presented in [23]. A publication for ICDAR2019 on the task of structure analysis is considered. Several follow up to improve the graph construction and use of fuzzy features will be tested. The creation of a prototype for the 2019 academic year for a first test in primary school is also planned.

4.9 Incremental learning with brutal concept drifts anticipation: Application to on-the-fly gestures recognition

Participants: Clément Leroy, Eric Anquetil, Nathalie Girard.

This work follows the thesis of Manuel Bouillon [Bou16] which aim is to design at end an on-the-fly gestures-command-based recognition system. With this new work we focuses on a more fundamental aspect in incremental learning which is the adaptation and detection of concept drifts.

In the context of single-pass on-line learning in a non-stationary environment, all systems have to deal with adaptation and detection of concept drifts. However, there are different natures of drifts (gradual drifts, brutal drifts...) often leading to different conflicting methods to detect and adapt the system regarding the drift nature. The on-the-fly gestures recognition apply to a command-gesture system is an ideal application context that meets the same problematics. Leaving the user free to choose his gestures and evolve at any time the set of gestures in a context of on-line gesture recognition make hard the recognition task. As the user can add

[Bou16] M. Bouillon, *Apprentissage actif en-ligne d'un classifieur évolutif, application à la reconnaissance de commandes gestuelles*, PdD Thesis, Université de rennes 1, 2016.

new gestures or change his way to make the gestures (in a conscious or unconscious way) the environment is non-stationary. The challenging difficulty here is to maintain good performance of the system in time, in particular when several drifts of different natures occur in the data stream.

In the evolving fuzzy system EFS (rules-based system using fuzzy inference rules), each rule should model the target concept. When a brutal drift occurs, a new rule should be created to catch the drifted concept. However, it takes time to detect the drift, and when it happens, it takes time for the newly created rule to model the drifted concept. To maintain good performance, we have proposed to anticipate a brutal drift inside each rule. An illustration of the system is given Figure 4.9.

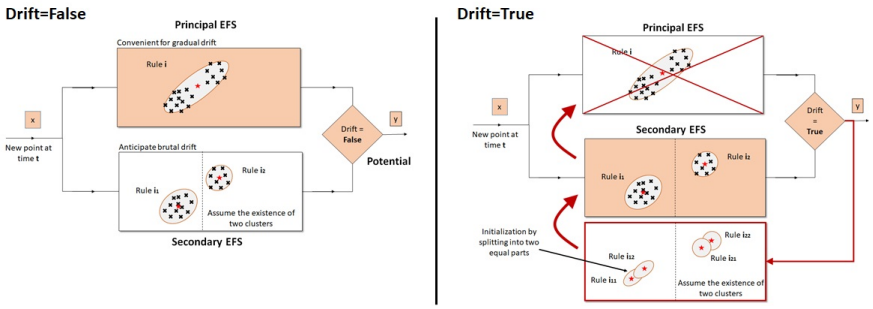


Figure 15: Scheme of our system where each rule of the principal EFS is linked with two rules of the second EFS. If no drift is detected, the output is given by the first system, else the ouput is given by the second EFS and the rule of the first system is replaced by the two rules of the second system.

To do it, each rule in the system is connected to a module which have already anticipated a separation of the rule into two new rules. One for the old concept and another one for the future possible new drifted concept. In such a way, the old rule and the new one are synchronously readjusted without saving any data. In addition, less time is needed to adapt the drifted concept, maintaining good performance all the time.
An evaluation of such system has been carried out in the context of on-the-fly recognition gestures applied to command-gesture system where the user is naturally non-stationary (he can add new gestures or he can change his way of drawing a gesture at any time). Two comparisons have been led, one with several benchmarks in the gestures recognition community, and another one with a standard evolving fuzzy system of the team (Evolve [Alm11]) over the same benchmark dataset where artificial brutal drifts are added. The results have been presented at the "Symposium International Francophone de l'Écrit et du Document" SIFED 2018 at Tours [22].

4.10 Fine Handwriting Quality Analysis: French and UK script and cursive letters

Participants: Damien Simonnet, Mickael Renault, Eric Anquetil, Nathalie Girard.

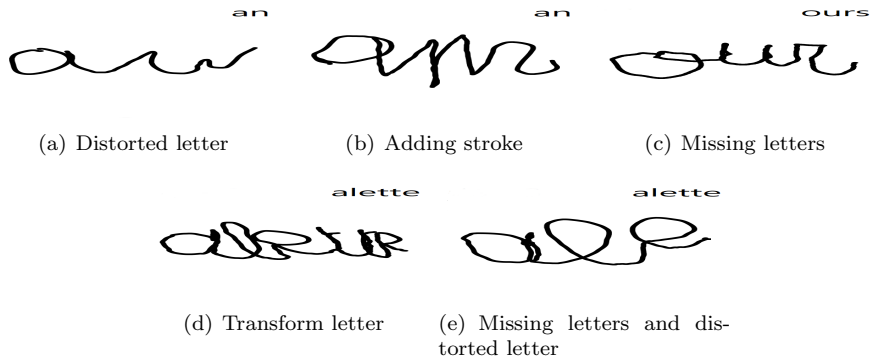
This work is coming from the ANR LabCom "ScriptAndLabs" activities (see section 6.2.1.

[Alm11] A. A. Almaksour, *Incremental Learning of Evolving Fuzzy Inference Systems : Application to Handwritten Gesture Recognition*, PdD Thesis, Université de rennes 1, 2011.

Following the works done in the *IntuiScript* project such as the definition of an analysis process of block letters, cursive letters, or block digits analysis [11][GSA17,AGS17]; the works done in the LabCom focused on the definition of an automatic qualitative analysis process of, one one hand, cursive handwriting words for french and, on the other hand, script and cursive letters for UK children.

4.10.1 Evaluation of french children cursive handwritten words

The proposed approach is original because the goal is not to recognise the word that was handwritten by children (since it is an explicit instruction) but to **design a precise evaluation of the quality of his handwriting production** to give children a real-time feedback. The main issue is the imprecision of the handwriting of young children. This scientific challenge of handwriting e-learning has been discussed and presented in an international collaborative paper in the journal *Pattern Recognition* [15].



(a) Distorted letter (b) Adding stroke (c) Missing letters

(d) Transform letter (e) Missing letters and distorted letter

Figure 16: Samples of Children approximate handwriting

In fact, when more than one letter is written, the evaluation implies to deal with the segmentation of a word in letters, and to identify matching, missing and added letters compared to the reference model. But this challenge is all the more complex in the context of the initial learning of the writing skills by children who have a very approximate handwriting. Indeed, they frequently add, distort, and even forget letters in the writing of a word. Moreover, children frequently combine several kinds of mistakes on the same word which makes the analysis task especially complex. As examples, Figure 16(a) shows a distorted letter problem in the writing of the word 'an' by a child, for the same word, Figure 16(b) shows an addition of stroke that can induce confusion between *n* and *m*. Other common errors lie in missing letters as illustrated in Figure 16(c) where the expected word is *ours* (*i.e.* bear). Figure 16(d) shows a letter transformation, where the last *e* of the pseudo-word *alette* has been transformed in an

[GSA17] N. Girard, D. Simonnet, E. Anquetil, "IntuiScript a new digital notebook for learning writing in elementary schools: 1st observations", *in: 18th International Graphonomics Society Conference (IGS2017)*, *Proceedings of IGS 2017*, p. 201–204, Gaeta, Italy, June 2017, `https://hal.inria.fr/hal-01548200`.

[AGS17] E. Anquetil, N. Girard, D. Simonnet, "IntuiScript : suivi et aide à l'apprentissage de l'écriture", *in: Symposium International sur la Littératie à l'Ecole / International Symposium for Educational Literacy (SILE/ISEL)*, Ajaccio, Corse, France, June 2017, `https://hal.inria.fr/hal-01551684`.

r. Finally, Figure 16(e), where the expected pseudo-word is *alette*, shows mistakes combination with missing letters and letter distortion.

To deal with that imprecision the method is based on a specific explicit elastic letter spotting segmentation. More precisely, we propose to strengthen the common segmentation with verification steps based on specific analysis methods. To do so, as summarized in Figure 17, the evaluation of the handwritten word quality consists of three main steps: extraction of primary segmentation hypotheses, then extraction of letter hypotheses and finally word hypothesis extraction and evaluation.

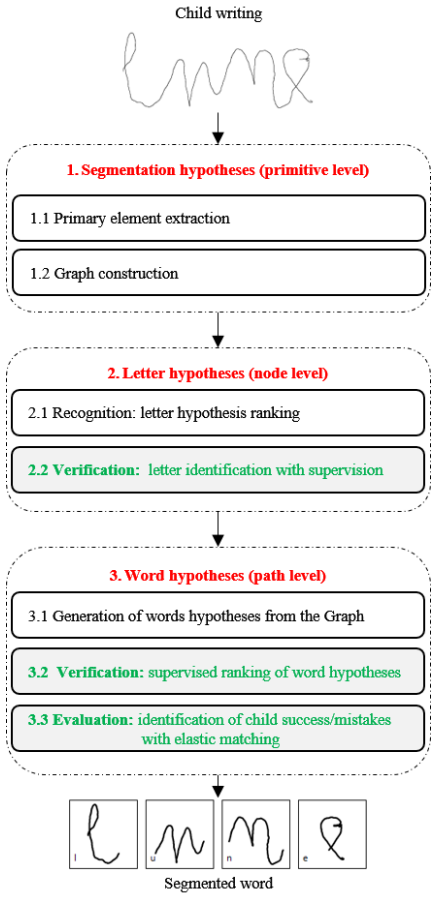


Figure 17: Automatic Cursive Handwriting Evaluation overflow in which the expected word is 'lune' (moon).

The validation of the proposed approach has been done on a dataset collected in French preschools and primary schools from 231 children. The quantitative results on the testing dataset correspond to a *correct segmentation ratio* of 0.90 in which a *letter average matching score* is of 0.95.

In Figure 18(a), results show that the presented method is able to segment children handwriting, and to identify additional strokes (#15 and #17) and some substitution (#20). However, although the segmentation is correct, some detected substitutions are incorrect (#14, #16) that

is due to deformed letters. Results on words presented in Figure 18(b) show the ability of the presented method to deal with longer sequences. Finally, errors in the segmentation presented in Figure 18(c) are mainly related to low handwriting quality of children (#0, #1, #2).

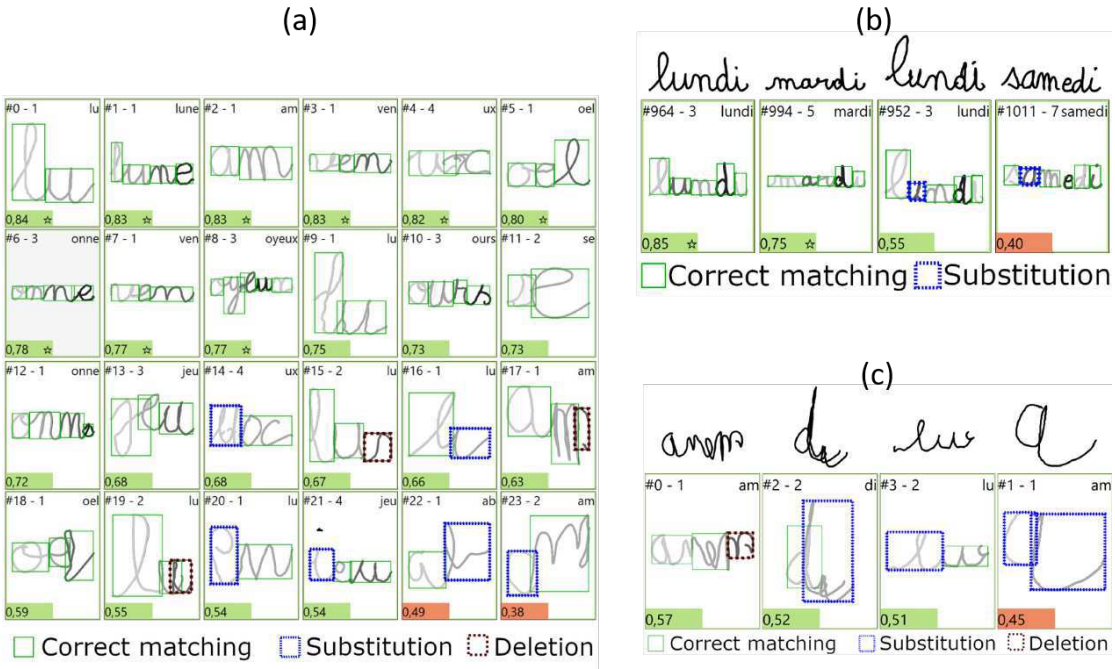


Figure 18: Qualitative Results. In (a), the segmentation of short handwritten sequences is represented with different grey scales. Green, blue and red bounding boxes correspond respectively to a letter with a correct matching, a substitution and a deletion. Similarly, in (b) Qualitative Results with handwritten words are presented. In (c), Errors of segmentation on children handwriting, the word that children should write is indicated on the top left corner.

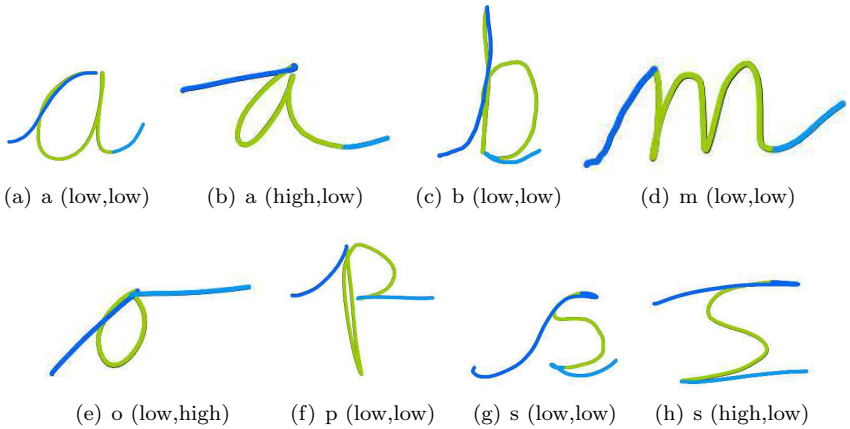
These results have been published in the journal *Pattern Recognition Letters* [16]

4.10.2 Handwriting Analysis of UK cursive and script letters

At the beginning, engines have been developed to analyse French cursive handwriting. The LabCom worked on an extension of the analysis engines to deal with cursive ans script handwriting used in the United Kingdom. The specificity of UK cursive handwriting is that children learn to write not only the morphological context of the letter but also ligatures with the previous and next letter as it is depicted in Figure 19.

To analyse the UK cursive handwriting, three specific engines have been developed:

- an analyser of the morphological context that evaluates the quality of the handwriting (shape and direction),
- an analyser of the left ligature that evaluates the quality of the shape and the position relatively to the morphological context,



(a) a (low,low) (b) a (high,low) (c) b (low,low) (d) m (low,low)

(e) o (low,high) (f) p (low,low) (g) s (low,low) (h) s (high,low)

Figure 19: Example of UK cursive letters composed of the morphological context (green), the left ligature (dark blue) and the right ligature (blue). Ligatures asked by the teacher can be low or high.

- an analyser of the right ligature that evaluates the quality of the shape and the position relatively to the morphological context.

First qualitative results are presented in Figure 20 and show that the score of left and right ligature decreases with the quality of the ligature. The morphological context analyser show also a coherent decreasing of the score with the handwriting quality as presented in Figure 21.

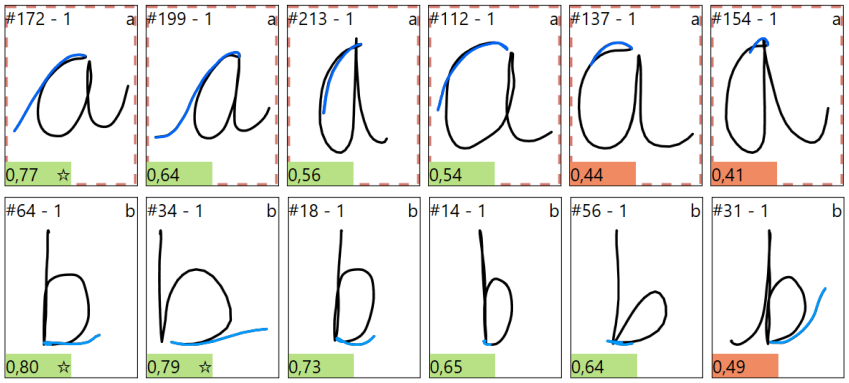


Figure 20: Qualitative analysis: of the left ligature (a) and the right ligature (b).

5 Software development

All the presented softwares have been deposit in APP. More details on those softwares can be found on Intuidoc web site (http://www.irisa.fr/intuidoc).

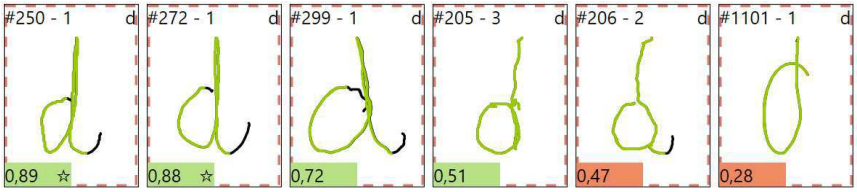


Figure 21: Qualitative results of the morphological context analyser.

5.1 RESIF: Handwriting recognition by hierarchical fuzzy inference systems

Eric Anquetil

Keywords: Handwriting Recognition, smartphone, fuzzy logic.

RESIF technology is composed of three main software to analyze, model and recognize handwritten characters and words:

- RESIFCar is specialized to recognize isolated handwritten characters: Latin alphabet, digits and special symbols.
- RESIFMot is the software for unconstrained cursive handwritten word recognition.
- RESIFApp is the automatic learning process that generates from a handwritten character database the hierarchical fuzzy models used by the recognition systems: RESIFCar and RESIFMot.

RESIFCar and RESIFApp are already in their fifth version. Through industrial collaborations, RESIFCar has been successfully integrated into mobile devices (smartphones) which are characterized by their limited computing and memory resources.

ResifCar has been integrated in the educational software *Toutaki* of Evodia/Script&Go Company. This Tablet PC software helps the young children to learn how to write. Toutaki has been licensed to HITACHI Company to be embedded to their Electronic Whiteboards.

Principles of Resif technology have inspired the conception in 2017-2018 of the new handwriting analyse software (DAP, ISA, ISF, IWA presented in section 5.2.

5.2 IA for Digital learning: Handwriting analysis software

Damien Simonnet, Mickael Renault, Eric Anquetil

Keywords: Handwriting Analysis, digital learning, fuzzy logic.

In the area of digital learning associated to the IntuiScript project and the ANR LabCom ScriptAndLabs (see section 6.2.1 and 4.10), we have developed four software:

- The ISF (Isolated Symbol Feature) software library allows the characterization of the meaning and direction of on-line manuscript tracing.
- The ISA (Isolated Symbol Analysis) software library allows the analysis of isolated symbols: capital letters, cursive letters, numbers

- The IWA (Isolated Word Analysis) software library enables the analysis and segmentation of handwritten words.
- The DAP (Drawing Precision Analysis) software library allows the analysis of the accuracy of a graphical plot against a guidance.

Through industrial collaboration with Learn&Go company, these software have been successfully integrated in the pen-based tablet solution: Kaligo. This solution is distributed by Learn&Go company. It is focused on learning writing at school from children aged 3 to 7.

5.3 EVOLVE++ / EVOLVE TOUCH: Evolving recognition engine

Eric Anquetil

Keywords: Incremental recognition, Evolving system, Gestures and Symbols Recognition.

Evolve++ is an evolving recognition engine, that can be trained incrementally, starting from few data samples. Evolve++ is based on a fuzzy inference systems that learn incrementally and cope with class adding.

Evolve-Touch is a derived software based on Evolve++ for the application domain of graphical gesture recognition for multi-touch devices. *Evolve-Touch* offer a complete framework to allow user to manage and customize his gesture sets for different application contexts in simple and user-friendly manner. An intuitive mechanism is adopted to get user feedback on recognizer answers, which allows the latter to continuously enhance its performance. In 2014 we focused on bringing a qualitative evaluation of gestures. To demonstrate the main features of Evolve-Touch system, a showcase application is presented in this video : *http://youtu.be/qOx4IY6uYf8*.

This work is supported by a *European Regional Development Fund* (FEDER), and protected by a *European and US patents* (N° 2995704 / 14/429,649).

In 2014, EvolveTouch was made available for *Android*, *WinRT* and *iOS* tablet systems.

Since 2018, Evolve is the IA engine integrated in the educational software *Kaligo* of Learn&Go company. Evolve engine has also been integrate in 2018 in the "IntuiDiag" software of Innax company.

The research on Evolving system based on Evolve technology is going on today with the new Phd student Clément Leroy (see 4.9).

5.4 Varchitect: Windows Store application based on Evolve++/EvolveTouch

Eric Anquetil

Keywords: Incremental recognition, Evolving system, Gestures and Symbols Recognition, Interior design, Tablet, Windows Store.

Varchitect is a Windows Store application that was developped as part of the effort to port the *Evolve++/EvolveTouch* system to current tablet operating systems. It is available for free at http://apps.microsoft.com/windows/en-us/app/aa0889d0-2097-4a91-aa28-2a74df7e206c

With Varchitect, users can define their own set of gesture commands to insert furniture or architectural elements in a plan, and then design their interior with a stylus or fingers. The

users can use a picture (taken from the tablet's builtin camera) as a base and set the scale of their plan to be sure everything fits. Plans made using Varchitect can be shared or printed.

This work is supported by a development fund from *SATT Ouest Valorisation*.

In 2015, Varchitect was downloaded more than 7000 times

5.5 DALI: a framework for the design of pen-based document sketching systems

Eric Anquetil

Keywords: Sketch recognition, pen-based interaction, visual language theory, industrial transfer.

DALI is a framework for the interpretation of hand-drawn sketches drawn on tablet PCs. The first property of the *DALI* method is its genericity, which means that it can be used to design pen-based software to sketch various natures of documents. It is based on the visual language and grammar theory that makes it possible to model bidimensional symbols and documents [9, 10]. *DALI* interprets the user strokes *on-the-fly*, directly during the design of the document; it means that each time the user draws a stroke, the system analyses it and produces a visual feedback, showing how it is interpreted.

This way, the user is an actor of the interpretation process, because he can progressively correct the errors of the system. Thus, the interpretation process can rely on the information given by the user to better interpret the following strokes. The coupling of these two properties increases significantly the efficiency and the robustness of the sketch interpretation process.

The *DALI* method has been used to design several pen-based prototypes, for instance for the sketching of musical scores, electrical sketches, UML class diagrams, architectural floor plans, etc.

It has been transferred to the Script&Go society, which led to the design of *Script&Go Electrical Sketches*. These softwares are today commercialized and used daily by hundreds of technicians in France. *Script&Go Electrical Sketches* has been rewarded with the "Trophées de l'innovation" 2008 for uses, applications and communicating solutions for enterprises", in the category named "Solutions Métiers".

In 2018, DALI framework has been extended to design Dplan library. The DPlan library allows the analysis and interpretation in real time of pen-based plan sketching on numeric tablet (walls, rooms, doors, windows...). Dplan library has been integrate in 2018 in the "IntuiDiag" software transferred to the Innax company. This transfer has been supported by a development fund from *SATT Ouest Valorisation* (see section 6.3.2).

5.6 DocRead : an automatic generator of recognition systems on structured documents

Bertrand Coüasnon

Keywords: Recognition, structured document, musical scores, mathematical formulae, table structures, forms, archives.

DocRead is an automatic generator of recognition systems on structured documents. It

has been developed thanks to the DMOS-P method [5]. It is made of a compiler of the EPF language (with which it is possible to describe a document), a parser associated to this language, an early vision module (binarization and line segments detection) and a classifier having also a reject option.

This generator allows us a fast adaptation to a new type of document. Indeed, it is only necessary to define a new grammar in EPF, which describes the new type of document. Then, if necessary, a new learning of the classifier is done to make it able to recognize new symbols. The new recognition system adapted to a new structured document is produced by compilation.

With this generator, we already have been able to produce recognition systems of structured documents:

- ScoRead: a prototype for musical scores recognition;
- MathRead: a prototype for mathematical formulae recognition;
- TennisRead: a prototype for tennis court detection in videos;
- TabRead: a prototype for table structures recognition;
- FormuRead: a software for reading military forms of the 19th century recognition despite their deterioration. This software has been successfully tested on more than 480,000 pages of the *Archives de la Mayenne* and *Archives des Yvelines*;
- NatuRead: a software for recognition of naturalization decree registers from 1883 to 1930. This software has been applied on 85,088 pages of the *Centre Historique des Archives Nationales*;
- LettRead: a software for extracting structure of mail documents. It has been applied on 1150 images provided by the French project RIMES.
- BanglaRead: a software for extracting headline in Bangla script. This extraction represent a pre-processing tool for handwritting recognition. This work has been realized in collaboration with University of Kolkata and applied on 1922 words from 26 writers.
- FlowRead: a sofwtare for on-line flow-chart segmentation and structure recognition.
- JournRead: a software for the recognition of old newspaper content structured in headlines, articles with title and author, graphics and tables. This software has been developed with a *SATT Ouest Valorisation* development fund;
- MaurdorRead: a software for the structure recognition of heterogeneous and multi-language documents, with handwritten, printed or mixed content. This software has been developed in the context of a PEA (Programme d'Etude Amont - upstream study program) from the DGA (French Ministry of Defense).

5.7 Precoce: Library to extract visual indices

Jean Camillerapp

Keywords: Early vision, adaptative binarization, vectorization, Kalman filtering, squeletonization, multi-resolution.

It is the library on which the DocRead software described in the section 5.6 is based.

This library is composed of various methods of adaptive binarization. Those use either local determinations of threshold or edge detection and region growing cooperation. Some of these methods can provide results with a sub-pixel resolution.

Using Kalman filters this library carries out detection of rectilinear segments in complex images.

It also contains a skeletonization method from gray level images.

The selected resolution for the digitalization of the documents is not always adapted at best to the recognition of all the structures. This is why the library also provides possibilities of multi-resolution processing.

5.8 LIMO : an isolated handwriting word recognizer

Bertrand Coüasnon

Keywords: Offline Handwriting Recognition, HMM, SVM, rejection.

The LIMO software purposes is to realize isolated handwriting word recognition. It takes as input an image of the word and produces a list of N-best hypotheses. It can be used to recognize words belonging to a finite dictionary or an open dictionary (with n-gram language model). The recognizer has a two stages architecture :

- A HMM-based recognition that generates a list of N-best hypotheses,
- A SVM-based verification to rescore the N-best hypotheses using SVM character classifiers and to select the best one.

The recognizer also has an integrated rejection feature which combines the HMM and SVM recognition scores to accept or reject the analyzed sample.

5.9 iLib: a feature extraction library

Yann Ricquebourg

Keywords: Feature extraction.

Concerning the studies of efficient classification and recognition methods, the team lacks its own library of low-level extraction of information that should feed the developed classifiers. Therefore, we decided to federate our works and join our algorithms extracting and computing features from images in a common framework.

Those main purposes have been achieved and the library now proposes in a generic and stable way “classical” features often cited as required by common recognition systems (as surface, gravity center, curvature...), as well as more original or promising characteristic functions as Zernike moments, (concerning plain pixel images), elliptic Fourier descriptors (concerning contour curves), or holes and hollows determination based on chanfrein distance and convex envelope.

Moreover, through a generic approach of our implementation, any extractor functions can be involved in a useful classical “zoning” computation, without requiring complementary programming of the extractor itself.

Additionally, the library also includes auxiliary data structures that are required by some feature extractors (Freeman chains, run-length representation...) as well as utility algorithms (adaptative binarisation, connected region labelling...).

Finally, motivated by our current perspective of experimenting CRFs on images, we are facing the difficulty to find implementations for general CRF use and able to process in the continuous domain of numerical data needed by image processing (whilst not theoretically compulsory, usual recommended implementations are restricted to symbolic data). To handle images, some implementations propose a workaround using a neuronal system to handle numeric data from images. But the CRF system is only on top of outputs of this subsystem, as a superior layer and as a posterior processing (RNNSharp from Microsoft, Hidden-Unit Conditional Random Fields, ...) Thus we work to add a fully numerical implementation of CRFs, from existing generic symbolic implementations (like CRF++ or Wapiti).

6 Contracts and collaborations

6.1 International Initiatives

6.1.1 EURHISFIRM: Historical high-quality company-level data for Europe

Participant: Bertrand Coüasnon, Aurélie Lemaitre, Nathalie Girard, Simon Bouvier

.

- Partners: Paris School of Economics (PSE)(Coordinator), Universiteit Antwerpen, Johann Wolfgang Goethe Universitat Frankfurt am Main, Erasmus Universiteit Rotterdam, Uniwersytet Ekonomiczny we Wroclawiu, The Queen's University of Belfast, Koninklijke Nederlandse Akademie van Wetenschappen – Knaw, Universidad Carlos III de Madrid, Université de Rouen Normandie, Institut National des Sciences Appliquées de Rennes, Gesis Leibniz-Institut Fur Sozialwissenschaften
- 36 months (2018-2020)
- Contract: INSA, H2020 InfraDev

EURHISFIRM designs a world-class research infrastructure (RI) to connect, collect, collate, align, and share detailed, reliable, and standardized long-term financial, governance, and geographical data on European companies.

EURHISFIRM enables researchers, policymakers, and other stakeholders to develop and evaluate effective strategies to promote investment, economic growth and job creation. The RI provides the tools for long-term analysis highlighting the dynamics of the past and the way those dynamics structure our present and future.

EURHISFIRM develops innovative models and technologies to spark a "Big data" revolution in historical social sciences and valorize Europe's cultural heritage.

In this project we work on building a system to extract high-quality data from historical serial printed sources, to address three issues: (i) lowering the costs of data extraction from the same source; (ii) lowering the cost of adaptation of the system from one source to the other; (iii) developing effective data validation process. Interactions between the system and experts

on the sources lay at the heart of the conception. We first started to work on the structure recognition of companies yearbooks.

6.2 National Initiatives

6.2.1 Script&Labs/ANR joint Laboratory (LabCom): On-line handwriting and drawing recognition and interpretation for active Learning in e-education

Participant: Eric Anquetil, Nathalie Girard, Damien Simonnet, Mickael Renault.

- Partner: *Learn&Go Company*
- 36 months (2017-2019).
- Contract: INSA
- Website: `https://scriptandlabs.irisa.fr/`

With the great success of the IntuiScript Project (BPI/PIA-2) (`https://www-intuidoc.irisa.fr/projet-intuiscript/`), we want to consolidate our implication in e-education to achieve innovative contribution based on pen-based tablet devices. In that way, we build a ANR joint laboratory (LabCom) between IntuiDoc and Learn&Go Company on this promising topic for a total amount of 1 562K€(6.15 ETP) with 300K€of grant.

This new structured partnership would have the goal to design new educational learning experience at school by using tablet and tactile digital devices: handwriting learning, generative drawing/sketching, on-line handwritten arithmetic expression, collaborative interaction using 2D gestures, document annotation...

The ScriptAndLabs Laboratory has been selected (from the 122 national LabCom) for an oral presentation of its activities for the "National LabCom days" in Paris in September 2018.

Following this presentation, we have been invited by the ANR President and CEO to present the ScriptAndLabs LabCom at the administration council of ANR the November 22, 2018.

The ScriptAndLabs Laboratory has presented its first research results by an inauguration on October 18, 2018 at the "Jacobin Convent" Palais des congrès in Rennes, as part of the "Learning Show" event.

Current activities are described in section 4.10.

6.2.2 Actif: Active Learning and Collaboration with Tablet Computer, Interactions and Feedbacks (e-Fran - National Innovative BPI Project)

Participant: Eric Anquetil, Nathalie Girard, Simon Corbillé, Omar Krichen.

- Partners: *LP3C*, *Loustic*, *Société Learn&Go*, *Saooti*, *Région Bretagne*, *Espe*, *espace des sciences*
- 48 months (2017-2020).
- Contract: INSA

The project "ACTIF" is one of the 22 selected national project from the "e-fran / innovative national project " call. This is a 4 years project (2017-2020) for a total amount of 1 143 856€, led by the LP3C of the University of Rennes 2. It carries on: "Active Learning and Collaboration with Tablet Computer, Interactions and Feedbacks".

One of the key topics in this project is to investigate how to encourage new learning strategy based on "active learning" and especially on "generative drawing" using pen-based numerical devices. The concept is to ask students to create drawings while reading text for causing generative processing that leads to better learning outcomes. The goal is to improve the learning of student by considering "learning" as a generative activity especially with collaborative/cooperative interaction. In the scope of digital learning, the potential induces by pen-based devices (tablet, TNI and new interactive screen) is really interesting. The goal is to investigate how we can automatically generate intelligent "corrective" or "predictive" individual and collective feedbacks to users by interpreting their drawing process: summarizing, mapping, sketching...

The IntuiDoc team will ensure all the design related to the analysis of graphic productions with one engineer, one postdoctoral researcher and one PhD student. They will work on the issues of "Generative Drawing" in the field of Geometry at secondary school.

We have presented the first research results of the e-Fran projects on January 30, 2019 in Rennes in the presence of Mrs Le Pellec Muller, Rector of the Brittany academic region.

Current activities are described in section 4.6 and 4.7.

6.2.3 eFil: e-Feedback for Interactive Lecture - Labex CominLabs project

Participant: Eric Anquetil, Nathalie Girard, Sébastien Thomas, Mickael Renault.

- Partner: *LP3C (University of Rennes 2)*, *LS2N (University of Nantes)*
- 24 months (2017-2019).
- Contract: INSA

The e-Fil Cominlabs project is based on CAMIA/KASSIS which is a new digital learning environment (workbook) for active learning with pen-based tablet. The goal of the eFIL Project is to optimize and to evaluate this digital learning environment in classroom settings during lectures (Optimizing with user-centered design). Traces will be collected and analyzed both to explore learning dynamics in classroom, and to provide a dashboard allowing instructors to monitor their activities during lectures as well as in-between sessions. The goal is to explore and analyze traces to monitor learning activities in classroom with Educational Data Mining and Learning Analytics.

Current activities are described in section 4.5.

6.2.4 HBDEX : Exploitation of Historical Big Data for Digital Humanities

Participant: Bertrand Coüasnon, Aurélie Lemaitre, Camille Guerry.

- Partners: Paris School of Economics (PSE), Université de Rouen Normandie (LITIS), CAMS-EHESS

- 48 months (2017-2021)
- Contract: INSA, ANR

This project focuses on massive historical data extraction for digital humanities, applied on financial data. The objective is to analyze masses of printed tabular data: daily stock exchange quotation lists for the "La Coulisse" Stock Exchange in Paris during the 19th and 20th century.

We work on modeling strategies of analysis for sequential data for using the redundancy between the successive days of listing and the consistency between the global sequences of data.

Current activities are described in section 4.3.

6.2.5 IAT: Artificial Intelligence for Administration

Participant: Bertrand Coüasnon, Aurélie Lemaitre, Solène Tarride.

- Partners: Ministère de l'intérieur
- 2 months (12/2018-01/2019)
- Contract: Université de Rennes 1

This contract, founded by the Ministère de l'intérieur and leaded by the Druid research team of Irisa, is focused on the application of Artificial Intelligence to administration. We work on the automatic extraction of information in digitized administrative forms.

6.3 Bilateral industry grants

6.3.1 Industrial software licensing with Learn&GO company

Participant: Eric Anquetil.

- Partners: *Learn&GO company*
- Since 2017
- Contract: INSA

The IntuiDoc team has close links with the Learn&GO company for transferring its research results for e-education. This partnership is now based on several licensing agreements. They cover various technologies of the Intuidoc team such as handwriting recognition and analysis.

This partnership is also supported by several collaborative projects: in particular the ANR LabCom "Script&Labs" and the *IntuiScript* BPI Project (http://intuiscript.com/).

Current activities are described in section 4.10.

6.3.2 Industrial software licensing with Innax company

Participant: Eric Anquetil.

- Partners: *Innax company and SATT*
- 6 month in 2018
- Contract: INSA
- Supported by a development fund from *SATT Ouest Valorisation*

During 2017, with have developed and transferred an end-to-end software("IntuiDiag") for pen-based plan sketching on numeric tablet (walls, rooms, doors, windows...). The DPlan library (5.5) and the Evolve technology(5.3) have been integrated in this software.

IntuiDiag software allows the analysis and interpretation in real time of pen-based plan sketching on numeric tablet (walls, rooms, doors, windows...) for mobile diagnostic application.

6.4 Collaborations

6.4.1 Rochester Institute of Technology, USA

Participants: Kwon-Young Choi, Bertrand Coüasnon, Yann Ricquebourg, Richard Zanibbi (RIT).

- Partner: Rochester Institute of Technology (Rochester, NY, USA).
- Since 2016

In collaboration with Richard Zanibbi from the Rochester Institute of Technology (RIT), Rochester, NY, USA, we work on interactive learning by combining deep learning technics, syntactical analysis and user interaction to introduce learning of segmentation. We propose to study the strong combination of deep learning and syntactical methods to build a document structure recognition system able to deal with segmentation problems by learning them. The syntactical part models the structure and brings complex context to the deep learning recognition. This collaboration is done through the co-supervising (Bertrand Coüasnon, Yann Ricquebourg and Richard Zanibbi) of the PhD of Kwon-Young Choi (see section 4.2).

7 Dissemination

7.1 Promoting scientific activities

7.1.1 Scientific Events Selection

- A. Lemaitre is member of the organization commitee of the International French Symposium on Document and Handwriting (SIFED 2018)

- E. Anquetil is member of the program committee of ICFHR 2018, the 16th International Conference on Frontiers in Handwriting Recognition.
- E. Anquetil is member of the program committee of LNCS post-proceedings (2018) of the paper of the International Workshop on Graphics Recognition and Graphical Document Analysis (GREC 2017).
- B. Coüasnon is member of the program committee of the 5th International Workshop on Historical Document Imaging and Processing (HIP 2019).
- B. Coüasnon is member of the program committee of the 2nd International Workshop on Open Services and Tools for Document Analysis (ICDAR-OST 2019).
- B. Coüasnon is member of the program committee of the Workshop on Industrial Applications of Document Analysis and Recognition (2019).

7.1.2 Journal

- E. Anquetil is a reviewer in 2018 of:
  - ACM IUI conference (Intelligent User Interfaces).
  - Pattern Recognition Letters (PRL) international journal.
  - IJDAR (International Journal on Document Analysis and Recognition).
  - Informatica (International Journal of Computing and Informatics).
- A. Lemaitre is a reviewer in 2018 of:
  - ICFHR (International Journal on Document Analysis and Recognition).
  - Project funding "Conseil régional de Nouvelle Aquitaine"
- N. Girard is a reviewer in 2018 of:
  - ImaVis (Image and Vision Computing);

7.1.3 Invited Talks

- N. Girard was an invited for a scientific seminar by the team IEIAH - LIUM in Laval : "IntuiScript : suivi et aide à l'apprentissage de l'écriture avec des tablettes – stylet.".
- B. Coüasnon gave an invited talk at the 2nd International Workshop on Pattern Analysis and Applications, Kolkata, India, January 2018.

7.1.4 Tutorials

- A. Lemaitre and B. Coüasnon animated a tutorial session at the symposium SIFED 2018 in Nantes : "DMOS - It's your turn".

7.1.5 Scientific Expertise

- B. Coüasnon is a reviewer in 2018 of:
  - Project funding "Partenariats Hubert Curien" (PHC).

7.1.6 Research Administration

- E. Anquetil is a member of the executive committee of the society GRCE : " Groupe de Recherche en Communication Écrite ".
- E. Anquetil and B. Coüasnon take part in the animation structure " SA 5.2-Écrit " of the Pôle 2: ICC (Interaction coopération et communication), Axe 5: " Communication orale, écrite et visuelle " du GDR-PRC CNRS I^3 (Information, Interaction, Intelligence).
- E. Anquetil, B. Coüasnon, J. Camillerapp and A. Lemaitre, take part in the activities of the society GRCE : " Groupe de Recherche en Communication Écrite ".
- E. Anquetil is a member of the steering committee of LOUSTIC laboratory of Rennes (laboratoire d'observation des usages des technologies de l'information et de la communication).
- E. Anquetil is an elected member of the 27e section of the CNU council of INSA.
- E. Anquetil is an elected member of the administration council of INSA.
- B. Coüasnon is member of the board of Valconum (Centre Européen de Valorisation Numérique).
- B. Coüasnon is an elected member of the laboratory council of the INSA component of IRISA.
- B. Coüasnon is scientific head of the Media and Interactions Department of IRISA.
- B. Coüasnon is member of the scientific board of Irisa.

7.2 Teaching, supervision

7.2.1 Teaching

The team is mainly made up of teachers who are very implied in activities of teaching. But a majority of lectures are not rattached to this research topic, so they are not mentioned here.

- E. Anquetil is program manager of the Master of Science *"Innovation and Entrepreunership"* of INSA and Rennes School of Business (RSB).
- E. Anquetil and N. Girard give lectures at Master-Research *d'informatique* of University of Rennes 1.
- E. Anquetil is in charge of the module "Analysis, Interpretation and Recognition of 2D (touch) and 3D Gestures for New Man-Machine Interactions" (AIR) of the Master-Research *d'informatique* of University of Rennes 1.
- E. Anquetil is in charge of the module "Motion Analysis and Gesture Recognition (2D / 3D)" (AMRG) of the Computer Science Dept. of INSA Rennes.
- B. Coüasnon is in charge of the module on professionalization adapted to research (PROF) of the Master-Research *d'informatique* of University of Rennes 1.
- B. Coüasnon was invited for two courses at Master-Research "New technologies applied to History" of the Ecole nationale des Chartes on : "Digital Documents: Textual Documents" and "Automatic Access to Old Documents", Paris, France.

7.2.2 Supervision

- PhD: S. Y. Boulahia, Online 3D actions recognition by analyzing the trajectories of human's skeleton, E. Anquetil, R. Kulpa, INSA Rennes, defended July 2018.
- PhD in progress: K.Y. Choi, Interactive combination of deep learning and syntactical methods for contextual segmentation and structure learning in document recognition, B. Coüasnon, Y. Ricquebourg, R. Zanibbi (RIT, Rochester, USA), INSA de Rennes, started October 2016.
- PhD in progress: O. Krichen, Real-time interpretation of geometrical sketches production for e-feedback generation in digital learning, E. Anquetil, N. Girard, INSA Rennes, started September 2017.
- PhD in progress: Camille Guerry, Historical big data: modelization of strategies to analyse collections of documents, B. Coüasnon, A. Lemaitre, S. Adam (Univ Rouen), INSA de Rennes, started October 2018.
- PhD in progress: C. Leroy, Incremental learning and evolving recognition system: application to on-the-fly recognition of handwritten gestures, E. Anquetil, N. Girard, INSA Rennes, started October 2018.
- PhD in progress: A. Lods, On-line analysis of handwritten arithmetic operation on digital tablet: Design of an innovative educational solution to improve learning arithmetic calculations in elementary school, E. Anquetil, S. Macé, INSA Rennes, started Febuary 2018.

7.2.3 Juries

- E. Anquetil was the president of the committee of the HDR of Nicholas JOURNET, Contributions à l'analyse d'images de documents : du pixel au document augmenté, Université de Bordeaux, novembre 2018.

- E. Anquetil was a member of the PhD committee of Bruno STUNER, Cohorte de Réseaux de Neurones Récurrents pour la Reconnaissance de l'Écriture, Université de ROUEN, juin 2018.

7.3 Popularization

The ScriptAndLabs LabCom activities (see 6.2.1) have been featured in several news bulletin:

- Journal "20 mintutes" (9/10/18):

  `https://www.20minutes.fr/societe/2356983-20181019-rennes-application-kaligo-ecriture-apprend-aussi-tablettes`

- Journal "Rennes Métropole" (19/11/18):

  `https://metropole.rennes.fr/kaligo-le-cahier-numerique-rennais`

- Radio France Inter: (23/01/19) 7h15:

  `https://www.franceinter.fr/emissions/le-zoom-de-la-redaction/le-zoom-de-la-redaction-23-janvier-2019`

7.4 Patent and Deposit of digital creations (APP)

7.4.1 Deposit of Digital creations (APP)

- E. Anquetil, R. Lagrange and M. Renault deposited a new digital creation, IntuiDiag IHM Record v1.53:
  IDDN.FR.001.500006.000.S.P.2018.000.31100
- E. Anquetil and O. Krichen deposited a new digital creation, DPlan Record v1.1.164:
  IDDN.FR.001.470014.000.S.P.2018.000.31100
- E. Anquetil, D. Simmonet and M. Renault deposited a new digital creation, DAP – Drawing Precision Analysis Record v1.0:
  IDDN.FR.001.390008.000.S.P.2018.000.31235
- E. Anquetil, D. Simmonet and M. Renault deposited a new digital creation, ISA - Isolated Symbol Analysis Record v1.0:
  IDDN.FR.001.390013.000.S.P.2018.000.31235
- E. Anquetil, D. Simmonet and M. Renault deposited a new digital creation, ISF – Isolated Symbole Feature Record v1.0:
  IDDN.FR.001.390012.000.S.P.2018.000.31235
- E. Anquetil, D. Simmonet and M. Renault deposited a new digital creation, IWA – Isolated Word Analysis Record v1.0:
  IDDN.FR.001.390010.000.S.P.2018.000.31235
- B. Coüasnon and A. Lemaitre updated xDMOS-P deposit, v10.2:
  IDDN.FR.001.030028.003.S.P.2010.000.10000
- A. Lemaitre, B. Coüasnon and C. Carton deposited a new digital creation, EPF-Flow v2.0:
  IDDN.FR.001.100031.000.S.A.2018.000.10000
- A. Lemaitre, B. Coüasnon and C. Carton deposited a new digital creation, EPF-Marriage Record v4.0:
  IDDN.FR.001.100030.000.S.A.2018.000.10000
- C. Carton, A. Lemaitre and B. Coüasnon updated EPD-Courrier deposit, v4.0:
  IDDN.FR.001.190013.001.S.P.2012.000.21000
- C. Carton, A. Lemaitre and B. Coüasnon deposited a new digital creation, EWO v1.0:
  IDDN.FR.001.100028.000.S.P.2018.000.10000
- A. Lemaitre and B. Coüasnon updated EPF-LDT deposit, v4.0:
  IDDN.FR.001.160008.002.S.A.2010.000.10000
- A. Lemaitre, B. Coüasnon, A. Maroneze updated DMOS-P_Stocha deposit, v2.1:
  IDDN.FR.001.190009.001.S.A.2012.000.10000
- B. Coüasnon updated DMOS-P_Compil deposit, v9.7:
  IDDN.FR.001.030029.003.S.P.2010.000.10000
- A. Lemaitre deposited a new digital creation, EPF-BMS v1.0:
  IDDN.FR.001.100033.000.S.1.2018.000.10000

- J. Camillerapp updated Vision Precoce deposit, v5.2: IDDN.FR.001.290002.003.S.P.2006.000.10000
- J. Camillerapp updates POI_mots deposit, v1.8: IDDN.FR.001.140024.000.S.P.2018.000.10000

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Doctoral dissertations and "Habilitation" theses

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