Institution: City University London

Unit of Assessment: 10 Mathematical Sciences

Title of case study: FINEX: a probabilistic expert system for forensic identification

1. Summary of the impact

The mathematical calculations for determining the likelihood of kinship between two individuals from their DNA profiles can be quite laborious and error prone, even when carried out by experts in the field. FINEX, an Expert System-based software programme to automate such calculations, was developed through research in Bayesian networks undertaken at City University London. The software can accurately and efficiently calculate kinship likelihoods within a minute or two, calculations that could take an expert half a day or more. The software was licensed to the UK Forensic Science Service (FSS), who used it among other applications to analyse DNA evidence leading to convictions for several serious and high profile criminal cases.

2. Underpinning research

The determination of the likelihood that two or more individuals are biologically related, based on their DNA profiles is of interest in both civil and criminal application. A common civil application occurs in a case of disputed paternity in which, for example, a mother claims that the father of her child is a certain male, but he denies this. A related criminal application is that of incest, for example when a man is suspected of fathering a child by his daughter. The establishment of relatedness of individuals is also important for immigration cases.

Research undertaken by Dr Robert Cowell (employed at City since 1995, now Senior Lecturer) in collaboration with colleagues has shown how to formulate complex problems of forensic DNA identification inference to address such questions in terms of Probabilistic Expert Systems (PESs). However, general purpose PES software is not particularly well-suited to the repetitive tasks of specifying an appropriate set of marker networks for a specific problem, editing the many local conditional probability tables and combining evidence from several genetic markers to evaluate likelihoods. Such software can be time-consuming and error-prone because of the number and sizes of the tables requiring specification in the Bayesian networks. Co-authors in the research were A. Philip Dawid (Professor of Statistics, University of Cambridge, now retired), Steffen L. Lauritzen FRS (Professor of Statistics, University of Oxford), David J. Spiegelhalter (Winton Professor of the Public Understanding of Risk, University of Cambridge) and Julia Mortera (Professor of Statistics, Roma Tre University, Italy).

The creation and development of a novel prototype computer programme, FINEX, overcame these problems. FINEX was originally written to automate the process of constructing Bayesian networks PESs and to provide a user-friendly interface by reproducing the usual genetic tree in the computer screen. The Bayesian network is used to structure a definite genetic problem (in our case, a disputed relationship) in terms of a graphical model (with elementary deterministic relations, probabilistic computational nodes and a query node). Later, FINEX was extended to carry out the calculations itself, without having to export the Bayesian networks to a separate piece of software for analysis.

FINEX allows a user to express the structure of a forensic identification problem in a quick and simple manner through the syntax of a high-level graphical specification language. This allows quite complex hypotheses to be entertained regarding the relationships of individuals which could be so complex that an expert forensic scientist could not do the calculations. The user of the programme specifies two or more hypothetical relationships and the software evaluates the likelihood of the hypothetical relationships between known genetic profiles being actual. Assessments are made based on the differences of the likelihoods of the hypotheses.

3. References to the research

Cowell R.G., Dawid A.P., Lauritzen S.L. & Spiegelhalter D.J. (1999) *Probabilistic Networks and Expert Systems*, New York: Springer-Verlag http://www.springer.com/statistics/statistical+theory+and+methods/book/978-0-387-98767-5

- Winner, 2002 DeGroot Prize, International Society for Bayesian Analysis, the only book prize in the field of statistics.
- 1924 Google citations [data retrieved 30/7/2013]

Cowell R.G. (2003). FINEX: a Probabilistic Expert system for forensic identification. *Forensic Science International,* 134(2-3), 196-206 10.1016/S0379-0738(03)00164-6

Cowell R.G. (2009). Validation of an STR peak area model. *Forensic Science International: Genetics*, 3(3), 193–199 10.1016/j.fsigen.2009.01.006

Cowell R.G., Lauritzen S.L. & Mortera J. (2007). Identification and Separation of DNA Mixtures using Peak Area Information, *Forensic Science International*, 166(1), 28-34 10.1016/j.forsciint.2006.03.021

Cowell R.G., Lauritzen S.L. & Mortera J. (2008). Probabilistic modelling for DNA mixture analysis, *Forensic Science International: Genetics Supplement Series*, 1(1), 640-642 10.1016/j.fsigss.2007.10.087

Cowell R.G. (2009). Efficient maximum likelihood pedigree reconstruction, *Theoretical Population Biology*, 76, 285–291 10.1016/j.tpb.2009.09.002

The work has been published in leading international journals in the field which apply a rigorous peer review process prior to publication of articles.

4. Details of the impact

Impact of the software

The FSS took an interest in the software leading to a licence agreement in 2005 with City University London for its use for development and commercial sales. The FSS was a government-owned company which provided scene-of-crime and forensic investigation services to the police force and government agencies of England and Wales, as well as other countries. These included the Crown Prosecution Service, HM Revenue and Customs, HM Coroners' Service, Ministry of Defence Police and British Transport Police in the UK and worldwide forensic services.

The FSS replaced the user interface of FINEX and added custom features such as automated report generation. The version of the software developed by the FSS was originally called FSS-ibd, later changed to FSS DNA Lineage.[1,2] An important development in the functionality of the DNA Lineage software by the FSS was the ability to carry out a database search for possible partial matches of close relatives to a previously given DNA profile, such as might be found at a crime scene. This procedure is known as familial searching. Although a crime scene DNA sample might not match anyone already in the national DNA database, the offender might be a close relative of someone whose information is in the database. A partial DNA match may aid in identifying the offender via their familial links. The FSS DNA Lineage programme can compare over 2,000 profiles per minute in such a database search. It was used routinely by the FSS in its work and was crucial in winning an immigration contract with Norway to provide a service testing the claims people make when they apply for visas on behalf of family members. In 2011, the UK police had used the software in around one hundred cases.[3]

The FSS had a dedicated Familial Searching Service unit. With the use of the FSS DNA Lineage software, the FSS was able to identify 19 offenders of cold cases leading to their conviction. One of the most notorious criminals to be found and convicted with the help of the software was David Newton, known as the Ilkley Moor rapist. He was convicted and sentenced to life imprisonment in

December 2008. DNA evidence linked an attack on a dog walker to a rape carried out nine years previously. Within 36 hours the FSS experts were able to link the Ilkley Moor Attack to the earlier crime in Leeds.[4]

The FSS lost market share as a result of increased use of competitive tendering by police forces for forensic services and it was closed in 2012. However prior to this it had developed a reputation as a pioneer in forensic software and technology, notably DNA interpretation, databasing and electronic forensics. The Government decision to close the Service, announced in 2010, drew criticism from international forensic scientists and victim campaigners for the potential damage that this would do to the UK criminal justice system.[5]

A Home Office document, '*Review of Research and Development in Forensic Science*'[6], outlined the potential future of the FSS before the ultimate decision was taken to dissolve the service. During the review the question was asked: 'Can you give good examples in the forensic science field of translation of research into practice?'. The answer given relates to the use of the FINEX software and its uptake by the FSS ([9] being a reference in the document to the work of Robert Cowell):

"*For example, a well-respected group of academic statisticians [9] have published models in peer reviewed journals...*"

This is followed by an explanation of a new model for DNA mixed profiles:

"*The FSS R&D statisticians have developed and validated a model for de-convolving DNA mixed profiles based on academic research. This model has been implemented into the FSS, providing consistency, robustness, and cost effectiveness for the taxpayer.*"

In the same document the FSS also cites its achievements as including*: "Development and implementation of FSS DNA LINEAGE for kinship analysis, award-winning DNA INSIGHT software for DNA interpretation…and FSS-ibd a validated DNA database solution."*

The FSS DNA Lineage software was favourably reviewed in a report by the Economist Intelligence Unit (EIU) in 2011.[3] Part of the Economist Group, the EIU is a respected producer of country and industry reports. The report says: *"New software is speeding up the work of forensic scientists working for police and immigration services across the world. Thanks to some elegant mathematics from a lecturer at City University London, they can now match up DNA samples to get answers much more quickly."*

In the article, Dr Maguire, then of the FSS, stated *"the software has been used in around a hundred cases so far and would help in crime scenes where speed is vital – such as the identification of multiple victims of an incident involving mass fatalities".* He explains that even if an exact DNA match is not forthcoming, Dr Cowell's software can be used to narrow the search based on near matches commonly found among close relatives. Dr Maguire says*: "Based on probabilities, Dr Cowell's model identifies the likelihood of genetic markers being passed on from father or mother as well as the very close sibling relationships."*[8]

With the closure of the FSS, the FSS DNA Lineage software has been taken over by the Home Office who intend to continue to use it in the UK in criminal and immigration casework. City University London has recently reached an agreement with the Home Office to enable the University to continue the development and commercial exploitation of the software. A licence agreement is currently being negotiated with a Spanish software vendor.

Other software

In addition to the commercial software licensed to the FSS, another piece of software, FRANz, has been constructed as a result of the underpinning research and made available in the public domain.[7] This can be used to reconstruct pedigrees of related individuals; the algorithm for which is described in the journal *Theoretical Population Biology.*

5. Sources to corroborate the impact

1. www.promega.com/~/media/files/resources/profiles%20in%20dna/1101/dna%20based%20kinship%20analysis.pdf?la=en (Article dated March 2008 describing the FSS DNA-Based Kinship Analysis service)
2. Maguire, Christopher, McCullum, L. A., Jones, K. E. and Storey, C. L. (2009) Developing a Likelihood Ratio Approach to 'Familial Searching' of a DNA Database Using the Advanced Functionality Of FSS-ibd. In: 20th International Symposium on Human Identification, 12-15 October 2009, Las Vegas, NV (*Mention of the City University London and FSS work in relation to the development of another 'familial searching tool; paper produced by the Forensic Science Service, Wetherby, West Yorkshire, UK)*
3. Hoare, Stephen (2011), Formula for Success, *The Economist Intelligence Unit*, Special Report, www.eiu.com/report_dl.asp?mode=fi&fi=924190877.PDF (also published in *In Business* magazine)
4. Woman, 52, fought for her life in rape attack, Bradford Telegraph and Argus, 18th December 2008
5. Axing of Forensic Science Service may lead to rise in miscarriages of justice, scientists warn, *The Observer* , 12 February 2012; and www.independent.co.uk/news/uk/crime/csi-chief-condemns-forensic-cuts-2179744.html 9 January 2011
6. The Home Office, 2011, Review of Research and Development in Forensic Science, p.54
7. FRANz Beta Pedigree Reconstruction *[Information retrieved 21 July 2013]*

Personal corroboration can also be provided on request from former FSS staff.