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# De-Identification of Personally Identifiable Information

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DRAFT

# De-Identification of Personally Identifiable Information

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66

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75

### Abstract

76 De-identification is the removal of identifying information from data. Several US laws,  
77 regulations and policies specify that data should be de-identified prior to sharing as a control to  
78 protect the privacy of the data subjects. In recent years researchers have shown that some de-  
79 identified data can sometimes be re-identified. This document summarizes roughly two decades  
80 of de-identification research, discusses current practices, and presents opportunities for future  
81 research.

82

### Keywords

83 De-identification; HIPAA Privacy Rule; k-anonymity; re-identification; privacy

84

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87

### Audience

88 This document is intended for use by officials, advocacy groups and other members of the  
89 community that are concerned with the policy issues involving the creation, use and sharing of  
90 data sets containing personally identifiable information. It is also designed to provide  
91 technologists and researchers with an overview of the technical issues in the de-identification of  
92 data sets. While this document assumes a high-level understanding of information system  
93 security technologies, it is intended to be accessible to a wide audience. For this reason, this  
94 document minimizes the use of mathematical notation.

95

### Note to Reviewers

96 NIST requests comments especially on the following:

- 97 • Is the terminology that is provided consistent with current usage?
- 98 • To what extent should this document's subject be broadened to discuss differential  
99 privacy and statistical disclosure limitation techniques?
- 100 • Should the glossary be expanded? If so, please suggest words, definitions, and  
101 appropriate citations.

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## 1 Introduction

Government agencies, businesses and other organizations are increasingly under pressure to make raw data available to outsiders. When collected data contain personally identifiable information (PII) such as names or Social Security numbers (SSNs), there can be a conflict between the goals of sharing data and protecting privacy. *De-identification* is one way that organizations can balance these competing goals.

De-identification is a process by which a data custodian alters or removes identifying information from a data set, making it harder for users of the data to determine the identities of the data subjects. Once de-identified, data can be shared with trusted parties that are bound by data use agreements that only allow specific uses. In this case, de-identification makes it easier for trusted parties to comply with privacy requirements. Alternatively, the de-identified data can be distributed with fewer controls to a broader audience. In this case, de-identification is a tool designed to assist privacy-preserving data publishing (PPDP).

De-identification is not without risk. There are many de-identification techniques with differing levels of effectiveness. In general, privacy protection improves as more aggressive de-identification techniques are employed, but less utility remains in the resulting data set. As long as any utility remains in the data, there exists the possibility that some information might be linked back to the original identities, a process called *re-identification*. The use of de-identified data can also result in other harms to the data subjects, even without having the data first re-identified.

### 1.1 Document Purpose and Scope

This document provides an overview of de-identification issues and terminology. It summarizes significant publications to date involving de-identification and re-identification.

### 1.2 Intended Audience

This document is intended for use by officials, advocacy groups and other members of the community that are concerned with the policy issues involving the creation, use and sharing of data sets containing personally identifiable information. It is also designed to provide technologists and researchers with an overview of the technical issues in the de-identification of data sets. While this document assumes a high-level understanding of information system security technologies, it is intended to be accessible to a wide audience. For this reason, this document minimizes the use of mathematical notation.

### 1.3 Organization

The remainder of this report is organized as follows: Section 2 introduces the concepts of de-identification, re-identification and data sharing models. Section 3 discusses *syntactic de-identification*, a class of de-identification techniques that rely on the masking or altering of fields in tabular data. Section 4 discusses current challenges of de-identification information that are not tabular data, such as free-format text, images, and genomic information. Section 5 concludes. Appendix A is a glossary, and Appendix B provides a list of additional resources.

## 2 De-identification, Re-Identification, and Data Sharing Models

This section explains the motivation for de-identification, discusses the use of re-identification attacks to gauge the effectiveness of de-identification, and describes models for sharing de-identified data. It also introduces the terminology used in this report.

### 2.1 Motivation

Increasingly organizations that are collecting data and maintaining databases are under challenged to protect the data while using and sharing as widely as possible. For government databases, data sharing can increase transparency, provide new resources to private industry, and lead to more efficient government as a whole. Private firms can also benefit from data sharing in the form of increased publicity, civic engagement, and potentially increased revenue if the data are sold.

When datasets contains personally identifiable information such as names, email addresses, geolocation information, or photographs, there can be a conflict between the goals of effective data use and privacy protection. Many data sharing exercises appear to violate the Fair Information Practice Principles<sup>1</sup> of *Purpose Specification*<sup>2</sup> and *Use Limitation*<sup>3</sup>. Retaining a database of personal information after it is no longer needed, because it was expensive to create and the data might be useful in the future, may be a violation of the *Data Minimization*<sup>4</sup> principle.

De-identification represents an attempt to uphold the privacy promise of the FIPPs while allowing for data re-use, with the justification that the individuals' will not suffer a harm from the use of their data because their identifying information has been removed from the dataset.

Several US laws and regulations specifically recognize the importance and utility of data de-identification:

- The Department of Education has held that the Family and Educational Records Privacy Act does not apply to de-identified student records. “Educational agencies and institutions are permitted to release, without consent, educational records, or information from educational records that have been de-identified through the removal of all personally identifiable information.”<sup>5</sup>

<sup>1</sup> National Strategy for Trusted Identities in Cyberspace, Appendix A—Fair Information Practice Principles. April 15, 2011. <http://www.nist.gov/nstic/NSTIC-FIPPs.pdf>

<sup>2</sup> “**Purpose Specification:** Organizations should specifically articulate the authority that permits the collection of PII and specifically articulate the purpose or purposes for which the PII is intended to be used.” Ibid.

<sup>3</sup> “**Use Limitation:** Organizations should use PII solely for the purpose(s) specified in the notice. Sharing PII should be for a purpose compatible with the purpose for which the PII was collected.” Ibid.

<sup>4</sup> “**Data Minimization:** Organizations should only collect PII that is directly relevant and necessary to accomplish the specified purpose(s) and only retain PII for as long as is necessary to fulfill the specified purpose(s).”

<sup>5</sup> Dear Colleague Letter about Family Educational Rights and Privacy Act (FERPA) Final Regulations, US Department of Education, December 17, 2008. <http://www2.ed.gov/policy/gen/guid/fpco/hottopics/ht12-17-08.html>



- 202 • The Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule allows  
203 de-identified medical records to be used without any restriction, provided that  
204 organizations distributing the records have no direct knowledge that the records can be  
205 re-identified.<sup>6</sup>
- 206 • The Health Information Technology for Economic and Clinical Health Act (HITECH  
207 Act) requirements for security and privacy explicitly do not apply to the “use, disclosure,  
208 or request of protected health information that has been de-identified.”<sup>7</sup>
- 209 • The Foodborne illness surveillance system is required to allow “timely public access to  
210 aggregated, de-identified surveillance data.”<sup>8</sup>
- 211 • Entities contracted by Health and Human Services to provide drug safety data must have  
212 the ability to provide that data in de-identified form.<sup>9</sup>
- 213 • Voluntary safety reports submitted to the Federal Aviation Submission are not protected  
214 from public disclosure if the data that they contain is de-identified.<sup>10</sup>

215 Each of these laws and regulations implicitly assume that it is possible to remove personally  
216 identifiable information from a data set in a way that protects privacy but still leaves useful  
217 information. They also assume that de-identified information will not be re-identified at a later  
218 point in time.

219 In practice many de-identification techniques are not able to provide such strong privacy  
220 guarantees. Section 3.2 and Section 3.5 discuss some of the well-publicized cases in which data  
221 that were thought to be properly de-identified were published and then later re-identified by  
222 researchers or journalists. The results of these re-identifications violated the privacy of the data  
223 subjects, who were not previously identified as being in the dataset. Additional privacy harms  
224 can result from the disclosure of specific attributes that the data set linked to the identities.

## 225 **2.2 Models for Privacy-Preserving use of Private Information**

226 Academics have identified two distinct models for making use of personally identifiable  
227 information in a database while protecting the privacy of the data subjects:

- 228 • ***Privacy Preserving Data Mining.*** In this model, data are not released, but are used  
229 instead for statistical processing or machine learning. The results of the calculations may  
230 be released in the form of statistical tables, classifiers, or other kinds of results.

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<sup>6</sup> 45 CFR 160, 45 CFR 162, and 45 CFR 164. See also “Combined Regulation Text of All Rules,” US Department of Health and Human Services, Office for Civil Rights, Health Information Privacy.  
<http://www.hhs.gov/ocr/privacy/hipaa/administrative/combined/index.html>

<sup>7</sup> 42 USC 17935

<sup>8</sup> 21 USC 2224

<sup>9</sup> 21 USC 355

<sup>10</sup> 49 USC 44735

- 231       • **Privacy Preserving Data Publishing.** In this model, data are processed to produce a new  
232       data product that is distributed to users.

233 Privacy Preserving Data Mining (PPDM) is a broad term for any use of sensitive information to  
234 publish public statistics. Statistical reports that summarize confidential survey data are an  
235 example of PPDM.

236 **Statistical Disclosure Limitation<sup>11</sup>** is a set of principles and techniques that have been developed  
237 by researchers concerned with the generation and publication of official statistics. The goal of  
238 disclosure limitation is to prevent published statistics from impacting the privacy of those  
239 surveyed. Techniques developed for disclosure limitation include generalization of reported  
240 information to broader categories, swapping data between similar entities, and the addition of  
241 noise in reports.

242 **Differential Privacy** is a set of techniques based on a mathematical definition of privacy and  
243 information leakage from operations on a data set by the introduction of non-deterministic  
244 noise.<sup>12</sup> Differential privacy holds that the results of a data analysis should be roughly the same  
245 before and after the addition or removal of a single data record (which is usually taken to be the  
246 data from a single individual). In its basic form differential privacy is applied to online query  
247 systems, but differential privacy can also be used to produce machine-learning statistical  
248 classifiers and synthetic data sets.<sup>13</sup>

249 Differential privacy is an active research area, but to date there have been few applications of  
250 differential privacy techniques to actual running systems. Two notable exceptions are the Census  
251 Bureau's "OnTheMap" website, which uses differential privacy to create reasonably accurate  
252 block-level synthetic census data;<sup>14</sup> and Fredrikson et al.'s study to determine the impact of  
253 applying differential privacy to a clinical trial that created a statistical model for correlating  
254 genomic information and warfarin dosage.<sup>15</sup> The Fredrikson study concluded that the models  
255 constructed using differential privacy gains came at the cost of would result negative clinical  
256 outcomes for a significant number of patients.

257 Privacy Preserving Data Publishing (PPDP) allows for information based on private data to be  
258 published, allowing other researchers to perform novel analyses. The goal of PPDP is to provide

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<sup>11</sup> Statistical Policy Working Paper 22 (Second version, 2005), Report on Statistical Disclosure Limitation Methodology, Federal Committee on Statistical Methodology, December 2005.

<sup>12</sup> Cynthia Dwork, Differential Privacy, in ICALP, Springer, 2006

<sup>13</sup> Marco Gaboardi, Emilio Jesús Gallego Arias, Justin Hsu, Aaron, Zhiwei Steven Wu, Dual Query: Practical Private Query Release for High Dimensional Data, Proceedings of the 31<sup>st</sup> International Conference on Machine Learning, Beijing, China. 2014. JMLR: W&CP volume 32.

<sup>14</sup> Abowd et al., "Formal Privacy Guarantees and Analytical Validity of OnTheMap Public-use Data," Joint NSF-Census-IRS Workshop on Synthetic Data and Confidentiality Protection, Suitland, MD, July 31, 2009.

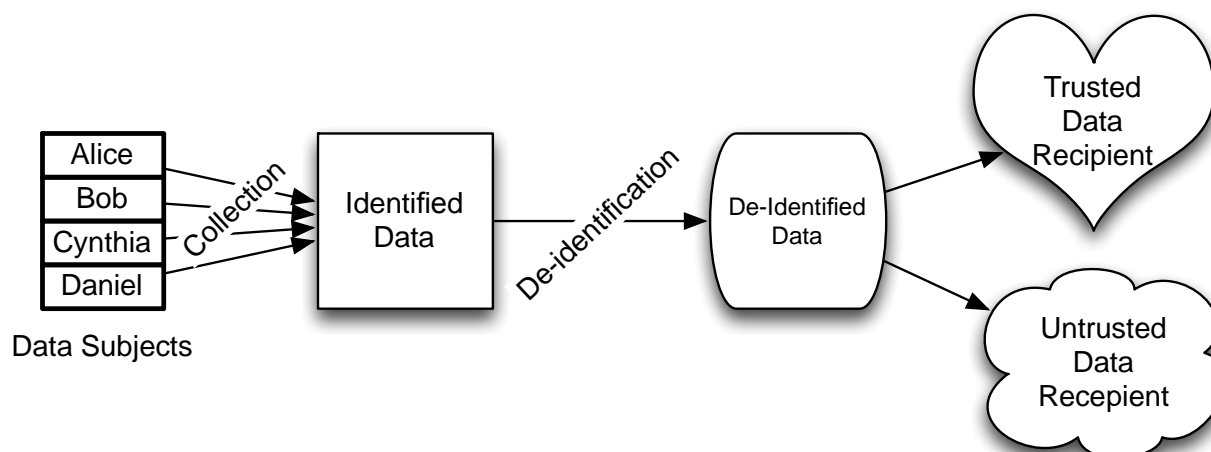
<sup>15</sup> Fredrikson et al., Privacy in Pharmacogenetics: An End-to-End Case Study of Personalized Warfarin Dosing, 23<sup>rd</sup> Usenix Security Symposium, August 20-22, 2014, San Diego, CA.

259 data that have high utility without compromising the privacy of the data subjects.

260 **De-identification** is the “general term for any process of removing the association between a set  
 261 of identifying data and the data subject.” (ISO/TS 25237-2008) De-identification is designed to  
 262 protect individual privacy while preserving some of the dataset’s utility for other purposes. De-  
 263 identification protects the privacy of individuals, making it hard or impossible to learn if an  
 264 individual’s data is in a data set, or to determine any attributes about an individual known to be  
 265 in the data set. De-identification is one of the primary tools for achieving PPDP.

266 **Synthetic data generation** uses some PPDM techniques to create a dataset that is similar to the  
 267 original data, but where some or all of the resulting data elements are generated and do not map  
 268 to actual individuals. As such synthetic data generation can be seen as a fusion of PPDM and  
 269 PPDP.

### 270 2.3 De-Identification Data Flow Model



271  
272

**Figure 1: Data Collection, De-Identification and Use**

273 Figure 1 provides an overview of the de-identification process. Data are collected from **Data**  
 274 **Subjects**, the “persons to whom data refer.” (ISO/TS 25237-2008) These data are combined into  
 275 a **data set** containing *personally identifiable information* (PII). De-identification creates a new  
 276 data set of *de-identified data*. This data set may eventually be used by a small number of trusted  
 277 data recipients. Alternatively, the data might be made broadly available to a larger (potentially  
 278 limitless) number of untrusted data recipients.

279 **Pseudonymization** is a specific kind of de-identification in which the direct identifiers are  
 280 replaced with pseudonyms (ISO/TS 25237:2008). If the pseudonymization follows a repeatable  
 281 algorithm, different practitioners can match records belonging to the same individual from  
 282 different data sets. However, the same practitioners will have the ability to re-identify the  
 283 pseudonymized data as part of the matching process. Pseudonymization can also be reversed if  
 284 the entity that performed the pseudonymization retains a table linking the original identities to  
 285 the pseudonyms, a technique called *unmasking*.

### 286 2.4 Re-identification Risk and Data Utility

287 Those receiving de-identified data may attempt to learn the identities of the data subjects that

288 have been removed. This process is called *re-identification*. Because an important goal of de-  
289 identification is to prevent unauthorized re-identification, such attempts are sometimes called *re-*  
290 *identification attacks*.

291 The term “attack” is borrowed from the literature of computer security, in which the security of a  
292 computer system or encryption algorithm is analyzed through the use of a hypothetical “attacker”  
293 in possession of specific skills, knowledge, and access. A risk assessment involves cataloging the  
294 range of potential attackers and, for each, the likelihood of success.

295 There are many reasons that an individual or organization might attempt a re-identification  
296 attack:

- 297 • **To test the quality of the de-identification.** For example, a researcher might conduct the  
298 re-identification attack at the request of the data custodian performing the de-  
299 identification
- 300 • **To gain publicity or professional standing for performing the de-identification.**  
301 Several successful re-identification efforts have been newsworthy and professionally  
302 rewarding for the researchers conducting them.
- 303 • **To embarrass or harm the organization that performed the de-identification.**  
304 Organizations that perform de-identification generally have an obligation to protect the  
305 personal information contained in the original data. As such, demonstrating that their  
306 privacy protecting measures were inadequate can embarrass or harm these organizations.
- 307 • **To gain direct benefit from the de-identified data.** For example, a marketing company  
308 might purchase de-identified medical data and attempt to match up medical records with  
309 identities, so that the re-individuals could be sent targeted coupons.

310 In the literature, re-identification attacks sometimes described as being performed by a  
311 hypothetical *data intruder* who is in possession of the de-identified dataset and some additional  
312 *background information*.

313 *Re-identification risk* is the measure of the risk that the identities and other information about  
314 individuals in the data set will be learned from the de-identified data. It is hard to quantify this  
315 risk, as the ability to re-identify depends on the original data set, the de-identification technique,  
316 the technical skill of the data intruder, the intruder’s available resources, and the availability of  
317 additional data that can be linked with the de-identified data. In many cases the risk of re-  
318 identification will increase over time as techniques improve and more background information  
319 become available.

320 Researchers have taken various approaches for computing and reporting the re-identification risk  
321 including:

- 322 • The risk that a specific person in the database can be re-identified. (The “prosecutor  
323 scenario.”)
- 324 • The risk that any person in the database can be re-identified. (The “journalist scenario.”)
- 325 • The percentage of identities in the database that is actually re-identified.

- 326       • The distinguishability between an analysis performed on a database containing an  
327       individual and on a database that does not contain the individual. (The “differential  
328       identifiability” scenario.<sup>16</sup>)

329 Likewise, different standards that have been used to describe the abilities of the “attacker”  
330 including:

- 331       • A member of general public who has access to public information on the web  
332       • A computer scientist skilled in re-identification (“expert”)  
333       • A member of the organization that produced the dataset (“insider”)  
334       • A friend or family member of the data subject  
335       • The data subject (“self re-identification”)

336 The purpose of de-identifying data is to allow some uses of the de-identified data while  
337 providing for some privacy protection. These two goals are generally antagonistic, in that there is  
338 a trade off between the amount of de-identification and the utility of the resulting data. The more  
339 securely the data are de-identified, the less utility remains. In general, privacy protection  
340 increases as more information is removed or modified from the original data set, but the  
341 remaining data are less useful as a result. It is the responsibility of those de-identifying to  
342 determine an acceptable trade-off.

343 A variety of harms that can result from the use or distribution of de-identified data, including:

- 344       • ***Incomplete de-identification.*** Identifiable private information may inadvertently remain  
345       in the de-identified data set. This was the case in search query data released by AOL in  
346       2006, in which journalists re-identified and contacted an AOL user through identifying  
347       information that the user had typed as search queries.<sup>17</sup>
- 348       • ***Identity disclosure*** (also called ***attribute disclosure*** and ***re-identification by linking***). It  
349       may be possible to re-identify specific records by linking some of the remaining data with  
350       similar attributes in another, identifying data set. De-identification is supposed to protect  
351       against this harm.
- 352       • ***Inferential disclosure.*** If a data set reveals that all individuals who share a characteristic  
353       have a particular attribute, and if the adversary knows of an individual in the sample who  
354       has that characteristic, then that individual’s attribute is exposed. For example, if a  
355       hospital releases information showing that all 20-year-old female patients treated had a  
356       specific diagnosis, and if Alice Smith is a 20-year-old female that is known to have been  
357       treated at the hospital, then Alice Smith’s diagnosis can be inferred, even though her

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<sup>16</sup> Jaewoo Lee and Chris Clifton. 2012. Differential identifiability. In Proceedings of the 18th ACM SIGKDD international conference on Knowledge discovery and data mining (KDD '12). ACM, New York, NY, USA, 1041-1049. DOI=10.1145/2339530.2339695 <http://doi.acm.org/10.1145/2339530.2339695>

<sup>17</sup> Barbaro M, Zeller Jr. T. A Face Is Exposed for AOL Searcher No. 4417749 New York Times. 9 August, 2006.

358 individual de-identified medical records cannot be distinguished from the others.<sup>18</sup> In  
359 general, de-identification is not designed to protect against inference-based attacks.

- 360 • **Association harms.** Even though it may not be possible to match a specific data record  
361 with an individual, it may be possible to associate an individual with the dataset as a  
362 whole or with a group of records within the dataset. That association may result in some  
363 kind of stigma for the data subject.
- 364 • **Group harms.** Even if it is not possible to match up specific data records with  
365 individuals, the data may be used to infer a characteristic and associate it with a group  
366 represented in the data.
- 367 • **Unmasking.** If the data were pseudonymized, it may be possible reverse the  
368 pseudonymization process. This might be done by using a table that shows the mapping  
369 of the original identities to the pseudonyms, by reversing the pseudonymization  
370 algorithm, or by performing a brute-force search in which the pseudonymization  
371 algorithm is applied to every possible identity until the matching pseudonym is  
372 discovered.

373 Organizations considering de-identification must therefore balance:

- 374 • The effort that the organization can spend performing and testing the de-identification  
375 process.
- 376 • The utility desired for the de-identified data.
- 377 • The harms that might arise from the use of the de-identified data.
- 378 • The ability to use other controls that can minimize the risk.
- 379 • The likelihood that an attacker will attempt to re-identify the data, and the amount of  
380 effort that the attacker might be willing to spend.

381 Privacy laws in the US tend to be concerned with regulating and thereby preventing the first two  
382 categories of harms—the release of incompletely de-identified data, and assigning of an identity  
383 to a specific record in the de-identified set. The other harms tend to be regulated by organizations  
384 themselves, typically through the use of Institutional Review Boards or other kinds of internal  
385 controls.

## 386 2.5 Release models and data controls

387 One way to limit the chance of re-identification is to place controls on the way that the data may  
388 be obtained and used. These controls can be classified according to different release models.  
389 Several named models have been proposed in the literature, ranging from no restrictions to  
390 tightly restricted. They are:

- 391 • **The Release and Forget model<sup>19</sup>:** The de-identified data may be released to the public,  
392 typically by being published on the Internet. It can be difficult or impossible for an  
393 organization to recall the data once released in this fashion.

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<sup>18</sup> El Emam Methods for the de-identification of electronic health records for genomic research. *Genome Medicine* 2011, 3:25  
<http://genomemedicine.com/content/3/4/25>



- 394 • **The Click-Through model**<sup>20</sup>: The de-identified data can be made available on the  
395 Internet, but the user must agree in advance to some kind of “click-through” data use  
396 agreement. In this event, an entity that performed and publicized a successful re-  
397 identification attack might be subject to shaming or sanctions.
- 398 • **The Qualified Investigator model**<sup>21</sup>: The de-identified data may be made available to  
399 qualified researchers under data use agreements. Typically these agreements prohibit  
400 attempted re-identifying, redistribution, or contacting the data subjects.
- 401 • **The Enclave model**<sup>22</sup>: The de-identified data may be kept in some kind of segregated  
402 enclave that accepts queries from qualified researchers, runs the queries on the de-  
403 identified data, and responds with results. (This is an example of PPDM, rather than  
404 PPDP.)

405 Gellman has proposed model legislation that would strengthen data use agreements.<sup>23</sup> Gellman’s  
406 proposal would recognize a new category of information *potentially identifiable personal*  
407 *information (PI<sup>2</sup>)*. Consenting parties could add to their data-use agreement a promise from the  
408 data provider that the data had been stripped of personal identifiers but still might be re-  
409 identifiable. Recipients would then face civil and criminal penalties if they attempted to re-  
410 identify. Thus, the proposed legislation would add to the confidence that de-identified data  
411 would remain so. “Because it cannot be known at any time whether information is re-  
412 identifiable, virtually all personal information that is not overtly identifiable is PI<sup>2</sup>,” Gellman  
413 notes.

### 414 3 Syntactic De-Identification Approaches and Their Criticism

415 *Syntactic de-identification techniques*<sup>24</sup> are techniques that attempt to de-identify by removing  
416 specific data elements from a data set based on element type. This section introduces the  
417 terminology used by such schemes, discusses the de-identification standard of the Health  
418 Insurance Portability and Privacy Act (HIPAA) Privacy Rule, and discusses critiques of the  
419 syntactic techniques and efforts that have appeared in the academic literature.

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<sup>19</sup> Ohm, Paul, Broken Promises of Privacy: Responding to the Surprising Failure of Anonymization. *UCLA Law Review*, Vol. 57, p. 1701, 2010

<sup>20</sup> K El Emam and B Malin, “Appendix B: Concepts and Methods for De-identifying Clinical Trial Data,” in *Sharing Clinical Trial Data: Maximizing Benefits, Minimizing Risk*, Institute of Medicine of the National Academies, The National Academies Press, Washington, DC. 2015

<sup>21</sup> Ibid.

<sup>22</sup> Ibid.

<sup>23</sup> Gellman, Robert; “The Deidentification Dilemma: A Legislative and Contractual Proposal,” July 12, 2010.

<sup>24</sup> Chris Clifton and Tamir Tassa, 2013. On Syntactic Anonymity and Differential Privacy. *Trans. Data Privacy* 6, 2 (August 2013), 161-183.

### 420 3.1 Removal of Direct Identifiers

421 Syntactic de-identification approaches are easiest to understand when applied to a database  
422 containing a single table of data. Each row contains data for a different individual.

423 **Direct identifiers**, also called *directly identifying variables* and *direct identifying data*, are “data  
424 that directly identifies a single individual.” (ISO/TS 25237:2008) Examples of direct identifiers  
425 include names, social security numbers and any “data that can be used to identify a person  
426 without additional information or with cross-linking through other information that is in the  
427 public domain.”<sup>25</sup> Many practitioners treat information such as medical record numbers and  
428 phone numbers as direct identifiers, even though additional information is required to link them  
429 to an identity.

430 Direct identifiers must be removed or otherwise transformed during de-identification. This  
431 processes is sometimes called *data masking*. There are at least three approaches for masking:

- 432 1) The direct identifiers can be removed.
- 433 2) The direct identifiers can be replaced with random values. If the same identify  
434 appears twice, it receives two different values. This preserves the form of the original  
435 data, allowing for some kinds of testing, but makes it harder to re-associate the data  
436 with individuals.
- 437 3) The direct identifiers can be systematically replaced with pseudonyms, allowing  
438 records referencing the same individual to be matched. Pseudonymization may also  
439 allow for the identities to be unmasked at some time in the future if the mapping  
440 between the direct identifiers and the pseudonyms is preserved or re-generated.

Direct Identifiers								
Name	Address	Birthday	ZIP	Sex	Weight	Diagnosis	...	...

441 **Table 1: A hypothetical data table showing direct identifiers**

442 Early efforts to de-identify databases stopped with the removal of direct identifiers.

### 443 3.2 Re-identification through Linkage

444 The *linkage attack* is the primary technique for re-identifying data that have been syntactically  
445 de-identified. In this attack, each record in the de-identified dataset is linked with similar records  
446 in a second dataset that contains both the linking information and the identity of the data subject.

447 Linkage attacks of this type were developed by Sweeney, who re-identified the medical records  
448 of Massachusetts governor William Weld as part of her graduate work at MIT. At the time  
449 Massachusetts was distributing a research database containing de-identified insurance

---

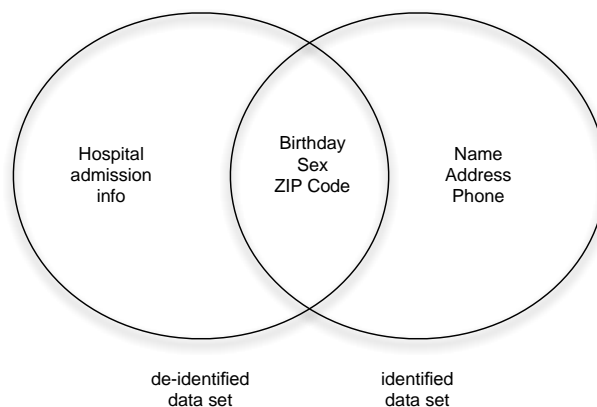
<sup>25</sup> ISO/TS 25237:2008(E), p.3



450 reimbursement records of Massachusetts state employees that had been hospitalized. To protect  
 451 the employees' privacy, their names were stripped from the database, but the employees' date of  
 452 birth, zip code, and sex was preserved to allow for statistical analysis.

453 Knowing that Weld had recently been treated at a Massachusetts hospital, Sweeney was able to  
 454 re-identify the governor's records by searching for the "de-identified" record that matched the  
 455 Governor's date of birth, zip code, and sex. She learned this information from the Cambridge  
 456 voter registration list, which she purchased for \$20. Sweeney then generalized her findings,  
 457 arguing that up to 87% of the US population was uniquely identified by 5-digit ZIP code, date of  
 458 birth, and sex.<sup>26</sup>

459 Sweeney's linkage attack can be demonstrated graphically:



460

461 **Figure 2: Linkage attacks combine information from two or more data sets to re-identify records**

462 Many factors complicate such linkage attacks, however;

- 463 • In order to be linkable, a person needs to be in both data sets. Sweeney knew that Weld  
 464 was in both data sets.
- 465 • Only records that are uniquely distinguished by the linking variables in both sets can be  
 466 linked. In this case, a person's records can only be linked if no one else shares their same  
 467 birthday, sex and ZIP in either data set. As it turned out, no other person in Cambridge  
 468 shared Weld's date of birth.
- 469 • If the variables are not the same in both data sets, then the data must be normalized so  
 470 that they can be linked. This normalization can introduce errors. This was not an issue in  
 471 the Weld case, but it could be an issue if one dataset reported "age" and another reported  
 472 "birthday."
- 473 • Verifying whether or not a link is correct requires using information that was not used as  
 474 part of the linkage operation. In this case, Weld's medical records were verified using  
 475 newspaper accounts of what had happened.

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<sup>26</sup> Sweeney L., Simple Demographics Often Identify People Uniquely, Carnegie Mellon University, Data Privacy Working Paper 3, Pittsburgh, 2000. <http://dataprivacylab.org/projects/identifiability/paper1.pdf>

### 476 3.3 De-identification of Quasi-Identifiers

477 *Quasi-identifiers*, also called *indirect identifiers* or *indirectly identifying variables*, are  
 478 identifiers that by themselves do not identify a specific individual but can be aggregated and  
 479 “linked” with information in other data sets to identify data subjects. The re-identification of  
 480 William Weld’s medical records demonstrated that birthday, ZIP, and Sex are quasi-identifiers.

Direct Identifiers		Quasi-Identifiers						
Name	Address	Birthday	ZIP	Sex	Weight	Diagnosis	...	...

481 **Table 2: A hypothetical data table showing direct identifiers and quasi-identifiers**

482 Quasi-identifiers pose a significant challenge for de-identification. Whereas direct identifiers can  
 483 be removed from the data set, quasi-identifiers generally convey some sort of information that  
 484 might be important for a later analysis. As such, they cannot be simply masked.

485 Several approaches have been proposed for de-identifying quasi-identifiers:

- 486 1) **Suppression:** The quasi-identifier can be suppressed or removed. Removing the data  
 487 maximizes privacy protection, but decreases the utility of the dataset.
- 488 2) **Generalization:** The quasi-identifier can be reported as being within a specific range  
 489 or as a member of a set. For example, the ZIP code 12345 could be generalized to a  
 490 ZIP code between 12000 and 12999. Generalization can be applied to the entire data  
 491 set or to specific records.
- 492 3) **Swapping:** Quasi-identifiers can be exchanged between records. Swapping must be  
 493 handled with care if it is necessary to preserve statistical properties.
- 494 4) **Sub-sampling.** Instead of releasing an entire data set, the de-identifying organization  
 495 can release a sample. If only subsample is released, the probability of re-identification  
 496 decreases.<sup>27</sup>

497 *K-anonymity*<sup>28</sup> is a framework developed by Sweeney for quantifying the amount of  
 498 manipulation required of the quasi-identifiers to achieve a given desired level of privacy. The  
 499 technique is based on the concept of an *equivalence class*, the set of records that have the same  
 500 quasi-identifiers. A dataset is said to be *k-anonymous* if, for every combination of quasi-  
 501 identifiers, there are at least *k* matching records. For example, if a dataset that has the quasi-  
 502 identifiers birth year and state has *k=4* anonymity, then there are at least four records for every  
 503 combination of (birth year, state) combination. Successive work has refined *k-anonymity* by

<sup>27</sup> El Emam, Methods for the de-identification of electronic health records for genomic research, *Genome Medicine* 2011, 3:25  
<http://genomemedicine.com/content/3/4/25>

<sup>28</sup> Latanya Sweeney. 2002. *k-anonymity: a model for protecting privacy*. *Int. J. Uncertain. Fuzziness Knowl.-Based Syst.* 10, 5  
 (October 2002), 557-570. DOI=10.1142/S0218488502001648 <http://dx.doi.org/10.1142/S0218488502001648>

504 adding requirements for diversity of the sensitive attributes within each equivalence class<sup>29</sup>, and  
 505 requiring that the resulting data are statistically close to the original data<sup>30</sup>.

506 El Emam and Malin<sup>31</sup> have developed an 11-step process for de-identifying data based on the  
 507 identification of identifiers and quasi-identifiers:

- 508 • **Step 1: Determine direct identifiers in the data set.** An expert determines the elements  
 509 in the data set that serve only to identify the data subjects.
- 510 • **Step 2: Mask (transform) direct identifiers.** The direct identifiers are either removed or  
 511 replaced with pseudonyms.
- 512 • **Step 3: Perform threat modeling.** The organization determines “plausible adversaries,”  
 513 the additional information they might be able to use for re-identification, and the quasi-  
 514 identifiers that an adversary might use for re-identification.
- 515 • **Step 4: Determine minimal acceptable data utility.** In this step the organization  
 516 determines what uses can or will be made with the de-identified data, to determine the  
 517 maximal amount of de-identification that could take place.
- 518 • **Step 5: Determine the re-identification risk threshold.** The organization determines  
 519 acceptable risk for working with the data set and possibly mitigating controls.
- 520 • **Step 6: Import (sample) data from the source database.** Because the effort to acquire  
 521 data from the source (identified) database may be substantial, the authors recommend a  
 522 test data import run to assist in planning.
- 523 • **Step 7: Evaluate the actual re-identification risk.** The actual identification risk is  
 524 mathematically calculated.
- 525 • **Step 8: Compare the actual risk with the threshold.** The result of step 5 and step 7 are  
 526 compared.
- 527 • **Step 9: Set parameters and apply data transformations.** If the actual risk is less than  
 528 the minimal acceptable risk, the de-identification parameters are applied and the data is  
 529 transformed. If the risk is too high then new parameters or transformations need to be  
 530 considered.
- 531 • **Step 10: Perform diagnostics on the solution.** The de-identified data are tested to make  
 532 sure that it has sufficient utility and that re-identification is not possible within the  
 533 allowable parameters.
- 534 • **Step 11: Export transformed data to external data set.** Finally, the de-identified data  
 535 are exported and the de-identification techniques are documented in a written report.

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<sup>29</sup> A. Machanavajjhala, J. Gehrke, D. Kifer, and M. Venkatasubramanian. l-diversity: Privacy beyond k-anonymity. In Proc. 22nd Intl. Conf. Data Engg. (ICDE), page 24, 2006.

<sup>30</sup> Ninghui Li, Tiancheng Li, and Suresh Venkatasubramanian (2007). "t-Closeness: Privacy beyond k-anonymity and l-diversity". ICDE (Purdue University).

<sup>31</sup> K. El Emam and B. Malin, “Appendix B: Concepts and Methods for De-identifying Clinical Trial Data,” in Sharing Clinical Trial Data: Maximizing Benefits, Minimizing Risk, Institute of Medicine of the National Academies, The National Academies Press, Washington, DC. 2015

536 The chief criticism of de-identification based on direct identifiers and quasi-identifiers is that it is  
 537 difficult to determine which fields are identifying, and which are non-identifying data about the  
 538 data subjects. Aggarwal identified this problem in 2005, noting that when the data contains a  
 539 large number of attributes, “an exponential number of combinations of dimensions can be used  
 540 to make precise inference attacks... [W]hen a data set contains a large number of attributes  
 541 which are open to inference attacks, we are faced with a choice of either completely suppressing  
 542 most of the data or losing the desired level of anonymity.”<sup>32</sup>

543 Work since has demonstrated some of Aggarwal’s concerns: many seemingly innocuous data  
 544 fields can become identifying for an adversary that has the appropriate matching information  
 545 (see Section 3.5). Furthermore, values that cannot be used as quasi-identifiers today may become  
 546 quasi-identifiers in the future as additional datasets are developed and released. To accurately  
 547 assess re-identification risk, it is therefore necessary to accurately model the knowledge,  
 548 determination, and computational resources of the adversaries that will be attempting the re-  
 549 identification.

### 550 **3.4 De-identification of Protected Health Information (PHI) under HIPAA**

551 The Health Insurance Portability and Accountability Act of 1996 (HIPAA) Privacy Rule  
 552 describes two approaches for de-identifying Protected Health Information (PHI): The Expert  
 553 Determination Method (§164.514(b)(1)) and the Safe Harbor method (§164.514(b)(2)).

554 The “Expert Determination” method provides for an expert to examine the data and determine an  
 555 appropriate means for de-identification that would minimize the risk of re-identification. The  
 556 specific language of the Privacy Rule states:

557 “(1) A person with appropriate knowledge of and experience with generally accepted  
 558 statistical and scientific principles and methods for rendering information not individually  
 559 identifiable:  
 560 (i) Applying such principles and methods, determines that the risk is very small that the  
 561 information could be used, alone or in combination with other reasonably available  
 562 information, by an anticipated recipient to identify an individual who is a subject of the  
 563 information; and  
 564 (ii) Documents the methods and results of the analysis that justify such determination;  
 565 or”

566 The “Safe Harbor” method allows a covered entity to treat data as de-identified if it by removing  
 567 18 specific types of data for “the individual or relatives, employers, or household members of the  
 568 individual.” The 18 types are:

569 “(A) Names  
 570 (B) All geographic subdivisions smaller than a state, including street address, city,  
 571 county, precinct, ZIP code, and their equivalent geocodes, except for the initial three  
 572 digits of the ZIP code if, according to the current publicly available data from the Bureau

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<sup>32</sup> Charu C. Aggarwal. 2005. On  $k$ -anonymity and the curse of dimensionality. In *Proceedings of the 31st international conference on Very large data bases (VLDB '05)*. VLDB Endowment 901-909.

- 573 of the Census:
- 574 (1) The geographic unit formed by combining all ZIP codes with the same three initial  
575 digits contains more than 20,000 people; and
- 576 (2) The initial three digits of a ZIP code for all such geographic units containing 20,000  
577 or fewer people is changed to 000
- 578 (C) All elements of dates (except year) for dates that are directly related to an individual,  
579 including birth date, admission date, discharge date, death date, and all ages over 89 and  
580 all elements of dates (including year) indicative of such age, except that such ages and  
581 elements may be aggregated into a single category of age 90 or older
- 582 (D) Telephone numbers
- 583 (E) Fax numbers
- 584 (F) Email addresses
- 585 (G) Social security numbers
- 586 (H) Medical record numbers
- 587 (I) Health plan beneficiary numbers
- 588 (J) Account numbers
- 589 (K) Certificate/license numbers
- 590 (L) Vehicle identifiers and serial numbers, including license plate numbers
- 591 (M) Device identifiers and serial numbers
- 592 (N) Web Universal Resource Locators (URLs)
- 593 (O) Internet Protocol (IP) addresses
- 594 (P) Biometric identifiers, including finger and voiceprints
- 595 (Q) Full-face photographs and any comparable images
- 596 (R) Any other unique identifying number, characteristic, or code, except as permitted by  
597 paragraph (c) of this section [Paragraph (c) is presented below in the section “Re-  
598 identification”];”
- 599

600 In addition to removing these data, the covered entity must not “have actual knowledge that the  
601 information could be used alone or in combination with other information to identify an  
602 individual who is a subject of the information.”

603 The Privacy Rule is heavily influenced by Sweeny’s research, as evidenced by its citation of  
604 Sweeny’s research the rule’s specific attention to the quasi-identifiers identified by Sweeny (ZIP  
605 code and birthdate) for generalization. The Privacy Rule strikes a balance between the risk of re-  
606 identification and the need to retain some utility in the data set—for example, by allowing the  
607 reporting of the first 3 digits of the ZIP code and the year of birth. Researchers have estimated  
608 that properly applied, the HIPAA Safe Harbor rule seems to allow the identification probability  
609 of approximately 1.5%.<sup>33</sup>

610 The actual rate of re-identification may be lower in some cases. In 2010 the Office of the  
611 National Coordinator for Health Information Technology (ONC HIT) at the US Department of  
612 Health and Human Services conducted a test of the HIPAA de-identification standard. As part of

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<sup>33</sup> Jaewoo Lee and Chris Clifton, Differential Identifiability, KDD ’12, Aug. 12-16, 2012. Beijing, China.

613 the study, researchers were provided with 15,000 hospital admission records belonging to  
614 Hispanic individuals from a hospital system between 2004 and 2009. Researchers then attempted  
615 to match the de-identified records to a commercially available data set of 30,000 records from  
616 InfoUSA. Based on the Census data the researchers estimated that the 30,000 commercial  
617 records covered approximately 5,000 of the hospital patients. When the experimenters matched  
618 using Sex, ZIP3 (the first 3 digits of the ZIP code, as allowed by HIPAA), and Age, they found  
619 216 unique records in the hospital data, 84 unique records in the InfoUSA data, and only 20  
620 records that matched on both sides. They then attempted to confirm these matches with the  
621 hospital and found that only 2 were actual matches, which were defined as having the same 5-  
622 digit ZIP code, the same last name, same street address, and same phone number. This represents  
623 a re-identification rate of 0.013%; the researchers also calculate a more conservative re-  
624 identification risk of 0.22%.

625 HIPAA also allows the sharing of *limited data sets* that have been partially de-identified but still  
626 include dates, city, state, zip code, and age. Such data sets may only be shared for research,  
627 public health, or health care operations, and may only be shared with if a data use agreement is  
628 executed between the covered entities to assure for subject privacy.<sup>34</sup> At minimum, the data use  
629 agreements must require security safeguards, require that all users of the data be similarly  
630 limited, and prohibit contacting of the data subjects.

### 631 **3.5 Evaluation of Syntactic De-identification**

632 The basic assumption of syntactic de-identification is that some of the columns in a data set  
633 might contain useful information without being inherently identifying. In recent years a  
634 significant body of academic research has shown that this assumption is not true in some cases.

- 635 • **Netflix Prize:** Narayanan and Shmatikov showed in 2008 that in many cases the set of  
636 movies that a person had watched could be used as an identifier.<sup>35</sup> Netflix had released a  
637 de-identified data set of movies that some of its customers had watched and ranked as  
638 part of its “Netflix Prize” competition. The researchers showed that a set common movies  
639 could be used to link many records in the Netflix dataset with similar records in the  
640 Internet Movie Data Base (IMDB), which had not been de-identified. The threat scenario  
641 is that by rating a few movies on IMDB, a person might inadvertently reveal *all* of the  
642 movies that they had watched, since the IMDB data could be linked with the public data  
643 from the Netflix Prize.
- 644 • **Medical Tests:** Atreya et al. showed in 2013 that 5-7 laboratory results from a patient  
645 could be used “as a search key to discover the corresponding record in a de-identified  
646 biomedical research database.”<sup>36</sup> Using a dataset with 8.5 million laboratory results from  
647

---

<sup>34</sup> [http://privacyruleandresearch.nih.gov/pr\\_08.asp](http://privacyruleandresearch.nih.gov/pr_08.asp)

<sup>35</sup> Narayanan, Arvind and Shmatikov Vitaly: Robust De-anonymization of Large Sparse Datasets. IEEE Symposium on Security and Privacy 2008: 111-125

<sup>36</sup> Atreya, Ravi V, Joshua C Smith, Allison B McCoy, Bradley Malin and Randolph A Miller, “Reducing patient re-identification risk for laboratory results within research datasets,” J Am Med Inform Assoc 2013;20:95–101. doi:10.1136/amiajnl-2012-001026.



648 61,280 patients, the researchers found that four consecutive laboratory test results  
649 uniquely identified between 34% and 100% of the population, depending on the test. The  
650 two most common test results, CHEM7 and CBC, respectively identified 98.9% and  
651 98.8% of the test subjects. The threat scenario is that a person who intercepted a single  
652 lab identified lab report containing a CHEM7 or CBC result could use report to search  
653 the de-identified biomedical research database for other records belonging to the  
654 individual.

- 655
- 656 • **Mobility Traces:** Also in 2013, Montjoye et al. showed that people and vehicles could be  
657 identified by their “mobility traces” (a record of locations and times that the person or  
658 vehicle visited). In their study, trace data for 1.5 million individuals was processed, with  
659 time values being generalized to the hour and spatial data generalized to the resolution  
660 provided by a cell phone system (typically 10-20 city blocks). The researchers found that  
661 four randomly chosen observations of an individual putting them at a specific place and  
662 time was sufficient to uniquely identify 95% of the data subjects.<sup>37</sup> Space/time points for  
663 individuals can be collected from a variety of sources, including purchases with a credit  
664 card, a photograph, or Internet usage. A similar study performed by Ma et al. found that  
665 30%-50% of individuals could be identified with 10 pieces of side information.<sup>38</sup> The  
666 threat scenario is that person who revealed 5 place/time pairs (perhaps by sending email  
667 from work and home at four times over the course of a month) would make it possible for  
668 an attacker to identify their entire mobility trace in a publicly released data set.
  - 669
  - 670 • **Taxi Ride Data:** In 2014 The New York City Taxi and Limousine Commission released a  
671 dataset containing a record of every New York City taxi trip in 2013 (173 million in  
672 total). The data did not include the names of the taxi drivers or riders, but it did include a  
673 32-digit alphanumeric code that could be readily converted to each taxi’s medallion  
674 number. A data scientist intern at the company Neustar discovered that he could find  
675 time-stamped photographs on the web of celebrities entering or leaving taxis in which the  
676 medallion was clearly visible.<sup>39</sup> With this information the was able to discover the other  
677 end-point of the ride, the amount paid, and the amount tipped for two of the 173 million  
678 taxi rides. A reporter at the Gawker website was able to identify another nine.<sup>40</sup>

679 The experience with the Netflix Prize indicates and the laboratory results shows that many sets

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<sup>37</sup> Yves-Alexandre de Montjoye et al., Unique in the Crowd: The privacy bounds of human mobility, Scientific Reports 3 (2013), Article 1376.

<sup>38</sup> Ma, C.Y.T.; Yau, D.K.Y.; Yip, N.K.; Rao, N.S.V., "Privacy Vulnerability of Published Anonymous Mobility Traces," Networking, IEEE/ACM Transactions on , vol.21, no.3, pp.720,733, June 2013

<sup>39</sup> “Riding with the Stars: Passenger Privacy in the NYC Taxicab Dataset,” Anthony Tockar, September 15, 2014, <http://research.neustar.biz/author/atockar/>

<sup>40</sup> “Public NYC Taxicab Database Lets you See How Celebrities Tip,” J. K. Trotter, GAWKER, October 23, 2014. <http://gawker.com/the-public-nyc-taxicab-database-that-accidentally-track-1646724546>

680 of sensitive values might also be identifying, provided that there is sufficient range or diversity  
681 for the identifiers in the population. The experience with the taxi data shows that there are many  
682 unanticipated sources of data that might correlate with other information in the data record.

683 The taxi and mobility trace studies demonstrate the strong identification power of geospatial  
684 information. Since each person can only be at one place at one time, just a few observations of a  
685 person's location and time can be highly identifying, even in a data set that generalized and  
686 noisy. Furthermore, some locations are highly identifying—either because they are isolated or  
687 well photographed.

688 However, the medical tests and taxi studies also show that relatively small changes to the data  
689 may make re-identification difficult or impossible. Atreya et al. demonstrated this directly. In  
690 the case of the Taxi data, the celebrities were only identified because the taxi medallion number  
691 pseudonymization could be unmasked, and the main privacy impact was the release of the  
692 specific geographical locations and tip amounts. If the medallion number had been properly  
693 protected and if the GPS location data had be aggregated to a 100 meter square grid, the risk of  
694 re-identification would have been considerably reduced. As it was, the taxi data demonstrates  
695 that the risk of re-identification under the “journalist scenario” (which sees any failure as a  
696 significant shortcoming) may be high, but risk under the “prosecutor scenario” might be very  
697 low (11 out of 173 million).

698 Putting this information into context of real-world de-identification requirements is difficult. For  
699 example, the ONC HIT 2010 study only attempted to match using the specific quasi-identifiers  
700 anticipated by the HIPAA Privacy Rule—age in years, sex, and ZIP3. Atreya et al. used a  
701 different threat model, one in which the attacker was assumed to have the results of a laboratory  
702 test. The results of Atreya imply that *if* the ONC HIT study included laboratory test results, and *if*  
703 the attacker had a laboratory test report including the patient's name and seven or more test  
704 results, then there is an overwhelming probability that there is a specific set of records in the de-  
705 identified data that are an exact match. However, this test was never done, and many may feel  
706 that it is not a realistic threat model.

707 El Emam et al<sup>41</sup> reviewed 14 re-identification attempts published between 2001 and 2010. For  
708 each the authors determined whether or not health data had been included, the profession of the  
709 adversary, the country where the re-identification took place, the percentage of the records that  
710 had been re-identified, the standards that were followed for de-identification, and whether or not  
711 the re-identification had been verified. The researchers found that the successful re-identification  
712 events typically involved small data sets that had not been de-identified according to existing  
713 standards. As such, drawing scientific conclusions from these cases is difficult. In many cases  
714 the re-identification attackers have re-identified just a few records but stated that many more  
715 could be re-identified.

716 De-identification and PPDP are still possible, but require a more nuanced attention to the  
717 potential for re-identification of the data subjects. One approach is to treat all data in the dataset

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<sup>41</sup> K El Emam, E Jonker, L Arbuckle, B MalinB (2011) A Systematic Review of Re-Identification Attacks on Health Data. PLoS ONE 6(12): e28071. doi:10.1371/journal.pone.0028071



718 as quasi-identifiers and accordingly manipulate them to protect privacy. This is possible, but may  
 719 require developing specific technology for each different data type. For example, Atreya et al.  
 720 developed an “expert” algorithm that could de-identify the data by perturbing the test results with  
 721 minimal impact on diagnostic accuracy.<sup>42</sup>

### 722 **3.6 Alternatives to Syntactic De-identification**

723 An alternative to syntactic de-identification is to generate synthetic data or synthetic data sets  
 724 that are statistically similar to the original data but which cannot be de-identified because they  
 725 are not based on actual people. Synthetic data elements are widely used in statistical disclosure  
 726 controls—for example, by aggregating data into categories, suppressing individual cells, adding  
 727 noise, or swapping data between similar records.

## 728 **4 Challenges in De-Identifying Contextual Data**

729 Whereas the last chapter was concerned mostly with the de-identification of tabular or structured  
 730 data, this section concerns itself with the open challenges of de-identifying contextual data.

### 731 **4.1 De-identifying medical text**

732 Medical records contain significant amounts of unstructured text. In recent years there has been a  
 733 significant effort to develop and evaluate tools designed to remove the 18 HIPAA data elements  
 734 from free-format text using natural language processing techniques. The two primary techniques  
 735 explored have been rule-based systems and statistical systems. Rule-based systems tend to work  
 736 well for specific kinds of text but do not work well when applied to new domains. Statistical  
 737 tools generally perform less accurately and require labeled training data, but are easier to  
 738 repurpose to new domains.

739 Multiple factors combine to make de-identifying text narratives hard:

- 740 1) Direct identifiers such as names and addresses may not be clearly marked.
- 741 2) Important medical information may be mistaken for personal information and  
 742 removed. This is especially a problem for eponyms which are commonly used in  
 743 medicine to describe diseases (e.g. Addison’s Disease, Bell’s Palsy, Reiter’s  
 744 Syndrome, etc.)
- 745 3) Even after the removal of the 18 HIPAA elements, information may remain that  
 746 allows identification of the medical subject.
- 747 4) Medical information currently being released as “de-identified” frequently does not  
 748 conform to the HIPAA standard.

749 In general the best systems seem to exhibit overall accuracy between 95-98% compared to  
 750 human annotators. A study by Meystre, Shen et. al showed the automatically de-identified  
 751 records from the Veteran’s Administration were not recognized by the patient’s treating  
 752 professional.<sup>43</sup>

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<sup>42</sup> Atreya, *supra*.

<sup>43</sup> Meystre S et al., Can Physicians Recognize Their Own Patients in De-Identified Notes? In Health – For Continuity of Care C.

753 Several researchers have performed formal evaluations of de-identification tools:

- 754 • In 2012 Deleger et al at Cincinnati Children’s Hospital Medical Center tested The  
 755 MITRE Identification Scrubber Toolkit (MIST)<sup>44</sup> against MCRF, an in-house system  
 756 developed by CCHMC based on the MALLET machine-learning package. The reference  
 757 corpora were 3503 clinical notes selected from 5 million notes created at CCHMC in  
 758 2010, the 2006 i2b2 de-identification challenge corpus,<sup>45</sup> and the PhisyoNet corpus.<sup>46 47</sup>  
 759
- 760 • In 2013 Ferrández *et al* at the University of Utah Department of Biomedical Informatics  
 761 performed an evaluation of five automated de-identification systems against two  
 762 reference corpora. The test was conducted with the 2006 i2b2 de-identification challenge  
 763 corpus, consisting of 889 documents that had been de-identification and then given  
 764 synthetic data,<sup>48</sup> and a corpus of 800 documents provided by the Veterans Administration  
 765 that was randomly drawn from documents with more than 500 words dated between  
 766 4/01/2008 and 3/31/2009.  
 767
- 768 • In 2013 The National Library of Medicine issued a report to its Board of Scientific  
 769 Counselors entitled “Clinical Text De-Identification Research” in which the NLM  
 770 compared the performance of its internally developed tool, the NLM Scrubber (NLM-S),  
 771 with the MIT de-identification system (MITdeid) and MIST.<sup>49</sup> The test was conduct with  
 772 an internal corpus of 1073 Physician Observation Reports and 2020 Patient Study  
 773 Reports from the NIH Clinical Center.  
 774

775 Both the CCHMC and the University of Utah studies tested the systems “out-of-the-box” and  
 776 after they were tuned by using part of the corpus as training data. The Utah study found that  
 777 none of the de-identification tools worked well enough to de-identify the VHA records for public  
 778 release, and that the rule-based systems exceled for finding certain kinds of information (e.g.  
 779 SSNs and phone numbers), while the trainable systems worked better for other kinds of data.

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Lovis et al. (Eds.) © 2014 European Federation for Medical Informatics and IOS Press.

<sup>44</sup> Aberdeen J, Bayer S, Yeniterzi R, et al. The MITRE Identification Scrubber Toolkit: design, training, and assessment. *Int J Med Inform* 2010;79:849e59.

<sup>45</sup> Uzuner O, Luo Y, Szolovits P. Evaluating the state-of-the-art in automatic de- identification. *J Am Med Inform Assoc* 2007;14:550e63.

<sup>46</sup> Neamatullah I, Douglass MM, Lehman LW, et al. Automated de-identification of free-text medical records. *BMC Med Inform Decis Mak* 2008;8:32.

<sup>47</sup> Goldberger AL, Amaral LA, Glass L, et al. PhysioBank, PhysioToolkit, and Physionet: components of a new research resource for complex physiologic signals. *Circulation* 2000;101:E215e20.

<sup>48</sup> Uzuner O, Luo Y, Szolovits P. Evaluating the state-of-the-art in automatic de- identification. *J Am Med Inform Assoc* 2007;14:550e63.

<sup>49</sup> Kayaalp M et al, A report to the Board of Scientific Counselors, 2013, The Lister Hill National Center for Biomedical Communications, National Library of Medicine.

780 Although there are minor variations between the systems, they are all had similar performance.  
781 The NLM study found that NLM-S significantly outperformed MIST and MITdeid on the NLM  
782 data set, removing 99.2% of the tokens matching the HIPAA Privacy Rule. The authors  
783 concluded that the remaining tokens would not pose a significant threat to patient privacy.

784 It should be noted that none of these systems attempt to de-identify data beyond removal of the  
785 18 HIPAA data elements, leaving the possibility that individuals could be re-identified using  
786 other information. For example, regulations in both the US and Canada require reporting of  
787 adverse drug interactions. These reports have been re-identified by journalists and researchers by  
788 correlating reports of fatalities with other data sources, such as news reports and death registers.

## 789 **4.2 De-identifying Imagery**

790 Multimedia imagery such as still photographs, consumer videos and surveillance video pose  
791 special de-identification challenges because of the wealth of identity information they potentially  
792 contain. Similar issues come into play when de-identifying digital still imagery, video, and  
793 medical imagery (X-Rays, MRI scans, etc.)

794 In general there are a three specific identification concerns:

- 795 1) The image itself may contain the individual's name on a label that is visible to a  
796 human observer but readily difficult to detect programmatically.
- 797 2) The file format may contain metadata that specifically identifies the individual. For  
798 example, there may be a GPS address of the person's house, or the person's name  
799 may be embedded in a header.
- 800 3) The image may contain an identifying biometric such as a scar, a hand measurement,  
801 or a specific injury.

802 Early research had the goal of producing images in which the faces could not be reliably  
803 identified by face recognition systems. In many cases this is sufficient: blurring is used by  
804 Google Street View, one of the largest deployments of photo de-identification technology.<sup>50</sup>  
805 Google claims that its completely automatic system is able to blur 89% of faces and 94-96% of  
806 license plates. Nevertheless, journalists have criticized Google for leaving many faces  
807 unblurred<sup>51</sup> and for blurring the faces of religious effigies<sup>52, 53</sup>.

808 Some researchers have developed systems that can identify and blur bodies,<sup>54</sup> as research has

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<sup>50</sup> Frome, Andrea, et al, "Large-scale Privacy Protection in Google Street View," IEEE International Conference on Computer Vision (2009).

<sup>51</sup> Stephen Chapman, "Google Maps, Street View, and privacy: Try harder, Google," ZDNet, January 31, 2013. <http://www.zdnet.com/article/google-maps-street-view-and-privacy-try-harder-google/>

<sup>52</sup> Gonzalez, Robbie. "The Faceless Gods of Google Street View," io9, October 4, 2014. <http://io9.com/the-faceless-gods-of-google-street-view-1642462649>

<sup>53</sup> Brownlee, John, "The Anonymous Gods of Google Street View," Fast Company, October 7, 2014. <http://www.fastcodesign.com/3036319/the-anonymous-gods-of-google-street-view#3>

<sup>54</sup> Prachi Agrawal and P. J. Narayanan. 2009. Person de-identification in videos. In Proceedings of the 9th Asian conference on

809 shown that bodies are frequently identifiable without faces.<sup>55</sup> An experimental system can locate  
810 and remove identifying tattoos from still images.<sup>56</sup>

811 Blurring and pixilation have the disadvantage of creating a picture that is visually jarring. Care  
812 must be taken if pixilation or blurring are used for obscuring video, however, as technology  
813 exists for de-pixelating and de-blurring video by combining multiple images. To address this,  
814 some researchers have developed systems that can replace faces with a composite face,<sup>57,58</sup> or  
815 with a face that is entirely synthetic.<sup>59,60</sup>

816 Quantifying the effectiveness of these algorithms is difficult. While some researchers may score  
817 the algorithms against face recognition software, other factors such as clothing, body pose, or  
818 geo-temporal setting might make the person identifiable by associates or themselves. A proper  
819 test of image de-identification should therefore include a variety of re-identification scenarios.

#### 820 **4.3 De-identifying Genetic sequences and biological materials**

821 Genetic sequences are not considered to be personally identifying information by HIPAA's de-  
822 identification rule. Nevertheless, because genetic information is inherited, genetic sequences  
823 have been identified through the use of genetic databanks even if the individual was not  
824 previously sequenced and placed in an identification database.

825 In 2005 a 15-year-old teenager used the DNA-testing service FamilyTreeDNA.com to find his  
826 sperm donor father. The service, which cost \$289, did not identify the boy's father, but it did  
827 identify two men who had matching Y-chromosomes. The two men had the same surname but  
828 with different spellings. As the Y-Chromosome is passed directly from father to son with no  
829 modification, it tends to be inherited the same way as European surnames. With this information  
830 and with the sperm donor's date and place of birth (which had been provided to the boy's

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Computer Vision - Volume Part III (ACCV'09), Hongbin Zha, Rin-ichiro Taniguchi, and Stephen Maybank (Eds.), Vol. Part III. Springer-Verlag, Berlin, Heidelberg, 266-276. DOI=10.1007/978-3-642-12297-2\_26 [http://dx.doi.org/10.1007/978-3-642-12297-2\\_26](http://dx.doi.org/10.1007/978-3-642-12297-2_26)

<sup>55</sup> Rice, Phillips, et al., Unaware Person Recognition From the Body when Face Identification Fails, *Psychological Science*, November 2013, vol. 24, no. 11, 2235-2243 <http://pss.sagepub.com/content/24/11/2235>

<sup>56</sup> Darijan Marčetić et al., An Experimental Tattoo De-identification System for Privacy Protection in Still Images, MIPRO 2014, 26-30 May 2014, Opatija, Croatia

<sup>57</sup> Ralph Gross, Latanya Sweeney, Jeffrey Cohn, Fernando de la Torre, and Simon Baker. In: *Protecting Privacy in Video Surveillance*, A. Senior, editor. Springer, 2009 *Preserving Privacy by De-identifying Facial Images*. <http://dataprivacylab.org/projects/facedeid/paper.pdf>

<sup>58</sup> E. Newton, L. Sweeney, and B. Malin. *Preserving Privacy by De-identifying Facial Images*, Carnegie Mellon University, School of Computer Science, Technical Report, CMU-CS-03-119. Pittsburgh: March 2003.

<sup>59</sup> Saleh Mosaddegh, Lóic Simon, Frederic Jurie. *Photorealistic Face de-Identification by Aggregating Donors' Face Components*. Asian Conference on Computer Vision, Nov 2014, Singapore. pp.1-16.

<sup>60</sup> Umar Mohammed, Simon J. D. Prince, and Jan Kautz. 2009. *Visio-lization: generating novel facial images*. In ACM SIGGRAPH 2009 papers (SIGGRAPH '09), Hugues Hoppe (Ed.). ACM, New York, NY, USA, Article 57, 8 pages. DOI=10.1145/1576246.1531363 <http://doi.acm.org/10.1145/1576246.1531363>

831 mother), the boy was able to identify his father using an online search service.<sup>61</sup>

832 In 2013 a group of researchers at MIT extended the experiment, identifying surnames and  
833 complete identities of more than 50 individuals who had DNA tests released on the Internet as  
834 part of the Study of Human Polymorphisms (CEPH) project and the 1000 Genomes Project.<sup>62</sup>

835 At the present time there is no scientific consensus on the minimum size of a genetic sequence  
836 necessary for re-identification. There is also no consensus on an appropriate mechanism to make  
837 de-identified genetic information available to researchers without the need to execute a data use  
838 agreement.

#### 839 **4.4 De-identification of geographic and map data**

840 De-identification of geographic data is not well researched. Current methods rely on perturbation  
841 and generalization. Perturbation is problematical in some cases, because perturbed locations can  
842 become nonsensical (e.g. moving a restaurant into a body of water). Generalization may not be  
843 sufficient to hide identity, however, especially if the population is sparse or if multiple  
844 observations can be correlated.

845 However, without some kind of generalization or perturbation there is so much diversity in  
846 geographic data that it may be impossible to de-identify locations. For example, measurement of  
847 cell phone accelerometers taken over a time period can be used to infer position by fitting  
848 movements to a street grid.<sup>63</sup> This is of concern because the Android and iOS operating systems  
849 do not consider accelerometers to be sensitive information.

#### 850 **4.5 Estimation of Re-identification Risk**

851 Practitioners are in need of easy-to-use procedures for calculating the risk of re-identification  
852 given a specific de-identification protocol. Calculating this risk is complicated, as it depends on  
853 many factors, including the distinctiveness of different individuals within the sampled data set,  
854 the de-identification algorithm, the availability of linkage data, and the range of individuals that  
855 might mount a re-identification attack.

856 There are also different kinds of re-identification risk. A model might report the average risk of  
857 each subject being identified, the risk that *any* subject will be identified, the risk that individual  
858 subjects might be identified as being 1 of *k* different individuals, etc.

859 Danker et al. propose a statistical model and decision rule for estimating the distinctiveness of  
860 different kinds of data sources.<sup>64</sup> El Emam et al. developed a technique for modeling the risk of

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<sup>61</sup> Sample, Ian. Teenager finds sperm donor dad on internet. The Guardian, November 2, 2005.  
<http://www.theguardian.com/science/2005/nov/03/genetics.news>

<sup>62</sup> Gymrek et al, Identifying Personal Genomes by Surname Inference, Science 18 Jan 2013, 339:6117.

<sup>63</sup> Jun Han; Owusu, E.; Nguyen, L.T.; Perrig, A.; Zhang, J., "ACComplice: Location inference using accelerometers on smartphones," *Communication Systems and Networks (COMSNETS), 2012 Fourth International Conference on*, pp.1,9, 3-7 Jan. 2012

<sup>64</sup> Dankar et al. Estimating the re-identification risk of clinical data sets, BMC Medical Informatics and Decision Making 2012, 12:66.

861 re-identifying adverse drug event reports based on two attacker models: a “mildly motivated  
862 adversary” whose goal is to identify a single record, and a “highly motivated adversary” that  
863 wishes to identify and verify all matches, “and is only limited by practical or financial  
864 considerations.”<sup>65</sup>

865 Practitioners are also in need of standards for acceptable risk. As previously noted, researchers  
866 have estimated that properly applied, the HIPAA Safe Harbor rule seems to allow the  
867 identification probability of approximately 1.5%.<sup>66</sup> El Emam and Alvarez are critical of the  
868 “Article 29 Working Party Opinion 05/2014 on data anonymization techniques” because the  
869 document appears to only endorse de-identification techniques that produce zero risk of re-  
870 identification.<sup>67</sup>

## 871 5 Conclusion

872 De-identification techniques can reduce or limit the privacy harms resulting from the release of a  
873 data set, while still providing users of the data with some utility.

874 To date, the two primary harms associated with re-identification appear to be damage to the  
875 reputation of the organization that performed the de-identification, and the discovery of private  
876 facts of people who were re-identified. Researchers or journalists performed most of the  
877 publicized re-identifications, and many of those re-identified were public figures.

878 Organizations sharing de-identified information should assure that they do not leave quasi-  
879 identifiers in the dataset that could readily be used for re-identification. They should also survey  
880 for the existence of linkable databases. Finally, organizations may wish to consider controls on  
881 the de-identified agreements that prohibit re-identification, including click-through licenses and  
882 appropriate data use agreements.

## 883 Appendix A Glossary

884 Selected terms used in the publication are defined below. Where noted, the definition is sourced  
885 to another publication.

886 **aggregated information:** Information elements collated on a number of individuals, typically  
887 used for the purposes of making comparisons or identifying patterns. (SP800-122)

888 **confidentiality:** “Preserving authorized restrictions on information access and disclosure,

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<sup>65</sup> El Emam et al., Evaluating the risk of patient re-identification from adverse drug event reports, BMC Medical Informatics and Decision Making 2013, 13:114 <http://www.biomedcentral.com/1472-6947/13/114>

<sup>66</sup> Jaewoo Lee and Chris Clifton, Differential Identifiability, KDD '12, Aug. 12-16, 2012. Beijing, China.

<sup>67</sup> Khaled El Emam and Cecelia Álvarez, A critical appraisal of the Article 29 Working Party Opinion 05/2014 on data anonymization techniques, International Data Privacy Law, 2015, Vol. 5, No. 1



- 889 including means for protecting personal privacy and proprietary information."<sup>68</sup>(SP800-122)
- 890 **Context of Use:** The purpose for which PII is collected, stored, used, processed, disclosed, or  
891 disseminated. (SP800-122)
- 892 **data linking:** “matching and combining data from multiple databases.” (ISO/TS 25237:2008)
- 893 **De-identification:** “General term for any process of removing the association between a set of  
894 identifying data and the data subject.” (ISO/TS 25237-2008)
- 895 **De-identified Information:** Records that have had enough PII removed or obscured such that  
896 the remaining information does not identify an individual and there is no reasonable basis to  
897 believe that the information can be used to identify an individual. (SP800-122)
- 898 **direct identifying data:** “data that directly identifies a single individual.” (ISO/TS 25237:2008)
- 899 **Distinguishable Information:** Information that can be used to identify an individual. (SP800-  
900 122)
- 901 **Harm:** Any adverse effects that would be experienced by an individual (i.e., that may be  
902 socially, physically, or financially damaging) or an organization if the confidentiality of PII were  
903 breached. (SP800-122)
- 904 **Healthcare identifier:** “identifier of a person for exclusive use by a healthcare system.” (ISO/TS  
905 25237:2008)
- 906 **HIPAA Privacy Rule:** “establishes national standards to protect individuals’ medical records  
907 and other personal health information and applies to health plans, health care clearinghouses, and  
908 those health care providers that conduct certain health care transactions electronically.” (HHS  
909 OCR 2014)
- 910 **identifiable person:** “one who can be identified, directly or indirectly, in particular by reference  
911 to an identification number or to one or more factors specific to his physical, physiological,  
912 mental, economic, cultural or social identity.” (ISO/TS 25237:2008)
- 913 **identifier** “information used to claim an identity, before a potential corroboration by a  
914 corresponding authenticator.” (ISO/TS 25237:2008)
- 915 **Limited data set:** A partially de-identified data set containing health information and some  
916 identifying information including complete dates, age to the nearest hour, city, state, and  
917 complete ZIP code.
- 918 **Linkable Information:** Information about or related to an individual for which there is a  
919 possibility of logical association with other information about the individual. (SP800-122)

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<sup>68</sup> 44 U.S.C. § 3542, <http://uscode.house.gov/download/pls/44C35.txt>.

- 920 **Linked Information:** Information about or related to an individual that is logically associated  
921 with other information about the individual. (SP800-122)
- 922 **Obscured Data:** Data that has been distorted by cryptographic or other means to hide  
923 information. It is also referred to as being masked or obfuscated. (SP800-122)
- 924 **personal identifier:** “information with the purpose of uniquely identifying a person within a  
925 given context.” (ISO/TS 25237:2008)
- 926 **personal data:** “any information relating to an identified or identifiable natural person (“data  
927 subject”)” (ISO/TS 25237:2008)
- 928 **Personally Identifiable Information (PII):** —“Any information about an individual maintained  
929 by an agency, including (1) any information that can be used to distinguish or trace an  
930 individual’s identity, such as name, social security number, date and place of birth, mother’s  
931 maiden name, or biometric records; and (2) any other information that is linked or linkable to an  
932 individual, such as medical, educational, financial, and employment information.”<sup>69</sup> (SP800-122)
- 933 **PII Confidentiality Impact Level:** The PII confidentiality impact level—low, moderate, or  
934 high—indicates the potential harm that could result to the subject individuals and/or the  
935 organization if PII were inappropriately accessed, used, or disclosed. (SP800-122)
- 936 **Privacy:** “freedom from intrusion into the private life or affairs of an individual when that  
937 intrusion results from undue or illegal gathering and use of data about that individual.” [ISO/IEC  
938 2382-8:1998, definition 08-01-23]
- 939 **Privacy Impact Assessment (PIA):** “An analysis of how information is handled that ensures  
940 handling conforms to applicable legal, regulatory, and policy requirements regarding privacy;  
941 determines the risks and effects of collecting, maintaining and disseminating information in  
942 identifiable form in an electronic information system; and examines and evaluates protections  
943 and alternative processes for handling information to mitigate potential privacy risks.”<sup>70</sup> (SP800-  
944 122)¶
- 945 **Protected Health Information:**
- 946 **Pseudonymization:** “particular type of anonymization that both removes the association with a  
947 data subject and adds an association between a particular set of characteristics relating to the data  
948 subject and one or more pseudonyms.” [ISO/TS 25237:2008]
- 949 **Pseudonym:** “personal identifier that is different from the normally used personal identifier.”  
950 [ISO/TS 25237:2008]

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<sup>69</sup> GAO Report 08-536, Privacy: Alternatives Exist for Enhancing Protection of Personally Identifiable Information, May 2008, <http://www.gao.gov/new.items/d08536.pdf>

<sup>70</sup> OMB M-03-22.



951 **Recipient:** “natural or legal person, public authority, agency or any other body to whom data are  
 952 disclosed.” [ISO/TS 25237:2008]

## 953 **Appendix B Resources**

### 954 **B.1 Official publications**

955 AU:

- 956 • Office of the Australian Information Commissioner, *Privacy business resource 4: De-*  
 957 *identification of data and information*, Australian Government, April 2014.  
 958 [http://www.oaic.gov.au/images/documents/privacy/privacy-resources/privacy-business-  
 resources/privacy\\_business\\_resource\\_4.pdf](http://www.oaic.gov.au/images/documents/privacy/privacy-resources/privacy-business-<br/>
    959 resources/privacy_business_resource_4.pdf)

960 EU:

- 961 • Article 29 Data Protection Working Party, 0829/14/EN WP216, Opinion 05/2014 on  
 962 Anonymisation Techniques, Adopted on 10 April 2014

963 ISO:

- 964 • ISO/TS 25237:2008(E) Health Informatics — Pseudonymization. Geneva, Switzerland.  
 965 2008. This ISO Technical Specification describes how privacy sensitive information can  
 966 be de-identified using a “pseudonymization service” that replaces direct identifiers with  
 967 pseudonyms. It provides a set of terms and definitions that are considered authoritative  
 968 for this document.

969 UK:

- 970 • UK Anonymisation Network, <http://ukanon.net/>
- 971 • Anonymisation: Managing data protection risk, Code of Practice 2012, Information  
 972 Commissioner’s Office. [https://ico.org.uk/media/for-  
 organisations/documents/1061/anonymisation-code.pdf](https://ico.org.uk/media/for-<br/>
    973 organisations/documents/1061/anonymisation-code.pdf). 108 pages

974 US:

- 975 • McCallister, Erika, Tim Grance and Karen Scarfone, *Guide to Protecting the*  
 976 *Confidentiality of Personally Identifiable Information (PII)*, Special Publication 800-122,  
 977 National Institute of Standards and Technology, US Department of Commerce. 2010.
- 978 • US Department of Health & Human Services, Office for Civil Rights, Guidance  
 979 Regarding Methods for De-identification of Protected Health Information in Accordance  
 980 with the Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule,  
 981 2010.
- 982 • Data De-identification: An Overview of Basic Terms, Privacy Technical Assistance  
 983 Center, US Department of Education. May 2013.  
 984 [http://ptac.ed.gov/sites/default/files/data\\_deidentification\\_terms.pdf](http://ptac.ed.gov/sites/default/files/data_deidentification_terms.pdf)

- 985 • Statistical Policy Working Paper 22 (Second version, 2005), Report on Statistical  
 986 Disclosure Limitation Methodology, Federal Committee on Statistical Methodology,  
 987 December 2005.

## 988 **B.2 Law Review Articles and White Papers:**

- 989 • Barth-Jones, Daniel C., The ‘Re-Identification’ of Governor William Weld's Medical  
 990 Information: A Critical Re-Examination of Health Data Identification Risks and Privacy  
 991 Protections, Then and Now (June 4, 2012). Available at SSRN:  
 992 <http://ssrn.com/abstract=2076397> or <http://dx.doi.org/10.2139/ssrn.2076397>  
 993 • Cavoukian, Ann, and El Emam, Khaled, De-identification Protocols: Essential for  
 994 Protecting Privacy, Privacy by Design, June 25, 2014.  
 995 [https://www.privacybydesign.ca/content/uploads/2014/06/pbd-de-](https://www.privacybydesign.ca/content/uploads/2014/06/pbd-de-identification_essential.pdf)  
 996 [identification\\_essential.pdf](https://www.privacybydesign.ca/content/uploads/2014/06/pbd-de-identification_essential.pdf)  
 997 • Lagos, Yianni, and Jules Polonetsky, Public vs. Nonpublic Data: the Benefits of  
 998 Administrative Controls, Stanford Law Review Online, 66:103, Sept. 3, 2013  
 999 • Ohm, Paul, Broken Promises of Privacy: Responding to the Surprising Failure of  
 1000 Anonymization (August 13, 2009). UCLA Law Review, Vol. 57, p. 1701, 2010; U of  
 1001 Colorado Law Legal Studies Research Paper No. 9-12. Available at SSRN:  
 1002 <http://ssrn.com/abstract=1450006>  
 1003 • Wu, Felix T. Defining Privacy and Utility in Data Sets, University of Colorado Law  
 1004 Review 84:1117 (2013).

## 1005 **B.3 Reports and Books:**

- 1006 • Committee on Strategies for Responsible Sharing of Clinical Trial Data, Board on Health  
 1007 Sciences Policy, *Sharing Clinical Trial Data: Maximizing Benefits, Minimizing Risk*,  
 1008 Institute of Medicine of the National Academies, The National Academies Press,  
 1009 Washington, DC. 2015.  
 1010 • Emam, Khaled El and Luk Arbuckle, *Anonymizing Health Data*, O'Reilly, Cambridge,  
 1011 MA. 2013

## 1012 **B.4 Survey Articles**

- 1013 • Chris Clifton and Tamir Tassa. 2013. On Syntactic Anonymity and Differential  
 1014 Privacy. *Trans. Data Privacy* 6, 2 (August 2013), 161-183.  
 1015 • Benjamin C. M. Fung, Ke Wang, Rui Chen and Philip S. Yu, Privacy-Preserving Data  
 1016 Publishing: A Survey on Recent Developments, *Computing Surveys*, June 2010.  
 1017 • Ebaa Fayyumi and B. John Oommen. 2010. A survey on statistical disclosure control  
 1018 and micro-aggregation techniques for secure statistical databases. *Softw. Pract.*  
 1019 *Exper.* 40, 12 (November 2010), 1161-1188. DOI=10.1002/spe.v40:12  
 1020 <http://dx.doi.org/10.1002/spe.v40:12>  
 1021 • Fayyumi, E. and Oommen, B. J. (2010), A survey on statistical disclosure control and  
 1022 micro-aggregation techniques for secure statistical databases. *Softw: Pract. Exper.*,  
 1023 40: 1161–1188. doi: 10.1002/spe.992