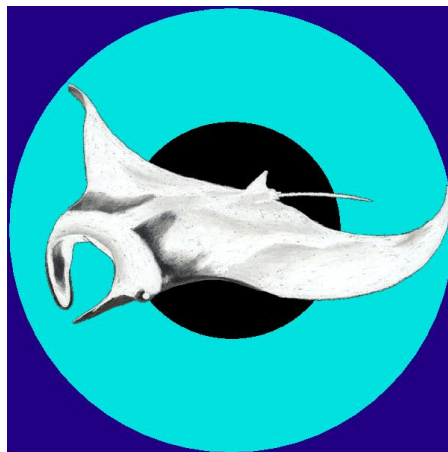


I³S SPOT MANUAL

**Interactive Individual Identification
System**



June 2014, version 4.0.2

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Interactive Individual Identification System - Spot version 4.0.2

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1 Introduction to I³S Spot

1.1 What is I³S Spot?

I³S is an acronym of Interactive Individual Identification System. The name explains most of I³S Spot's functionality. First, we will focus on the interactive part. I³S Spot requires user interaction and is meant to support and not to replace the researcher. Initially, you have to point out the location and shape of the spots of the unknown individual animal. In the next step, I³S Spot assists you in the tedious task of matching animals for identification purposes. It automatically matches an annotated image of an unknown animal with all annotated images in the identification database and shows a ranked list of images. However, you will always be responsible for making the final match between the unknown image and an image from the identification database. Please note that we distinguish between your database with all images taken and the identification database. The identification database should only contain the best images of known individuals and preferably 3 to 5 of each individual.

I³S Spot is based on I³S Manta 2.1, the second release in a series of related software tools. The first release, now called I3S Classic only allows annotation of spot centers and is used for animals with lots of similarly shaped spots such as whale sharks. This package focuses on animals with more spot variation. Instead of annotating the centers only, spots are annotated by the closest fitting ellipse around each spot, in this way taking spot size and shape into account. The third package was I³S Contour, which used the contour of e.g. flukes for identification. The fourth package, I³S Pattern, extracts key points automatically and should be used for animals with complex patterns where it is not possible to annotate separate spots easily and/or consistently.

We refer in the remainder of this manual to I³S Spot as I³S.

1.2 The algorithm

1.2.1 The reference points

To be able to correct for differences in viewing angle, rotation and scaling, the user is always required to point out three fixed reference points. The reference points should satisfy the following requirements:

1. Their exact location is consistently and clearly distinguishable.
2. Visible in all images.
3. The triangle made up by the three reference points should cover most of the region of interest used for identification. Ideally the triangle should have angles of 60 degrees. In most cases this will not be possible, but you should try to get as close as possible for optimal results.

1.2.2 Spot localization

To help recognize individual characteristics I³S requires the user to annotate each spot in the identification area with the closest fitting ellipse. The image should be taken ideally perpendicular to the line of sight and no more than 30 degrees off that line.

Once the spots are annotated, the collection of spots and reference points is stored in what is called a 'fingerprint file'. You recognize these files by the extension `.fgp`. In the identification step, the



resulting spot pattern is matched with the patterns of all the known animals in the identification database.

Figure 1.1 shows the reference points advised for a manta ray in blue. Do not mix-up these reference points as this will inhibit proper recognition. See section 4.1.3 if you want to change the names of the reference points.

Each new species will require careful selection of the three reference points as this is critical for performance of I³S. If you want to use I³S on a new species you are advised to consult the I³S team for support at: [i3s \[at\] reijns.com](mailto:i3s[at]reijns.com).

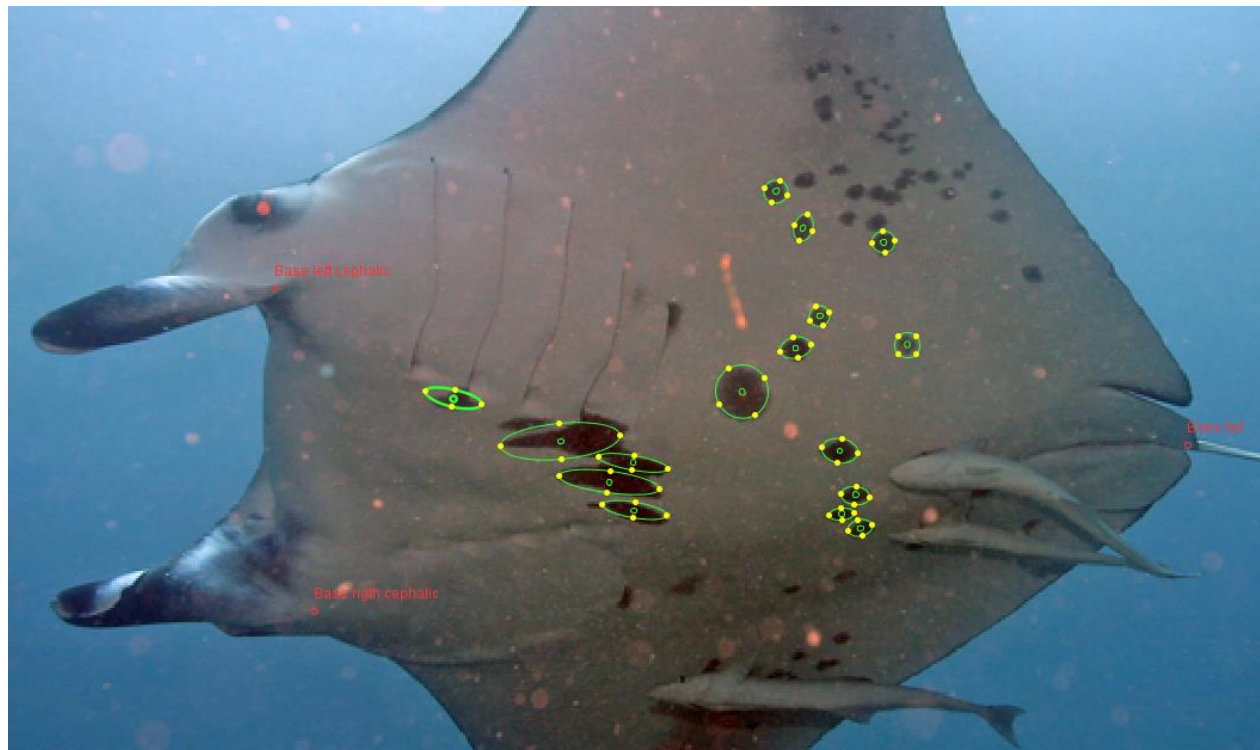


Figure 1-1: Manta ray with reference points and spots.
(Image source: Manta Trust)

1.2.3 Spot pattern comparison

With the reference points selected it is now possible to correct for rotation and scaling and compare two images in roughly the same 2D recognition space or coordinate system. A comparison of two images comes down to finding corresponding spot pairs in the above-mentioned coordinate system. In the current implementation a spot pair is accepted as a good match if the nearest other candidate is at sufficient distance from the current match.

Figure 1.2 shows the (centers of the) spots of two different images of the ray in this coordinate system. The red circles denote the spots of the first image while the blue circles represent the spots of the second image. The green lines indicate whether two spots are considered a matching pair. From these pairs a distance metric is calculated to be able to rank each image in the database. The current metric is the sum of the distances between each spot pair, divided by the square of the



number of spot pairs. When comparing two fingerprints I³S may generate thousands of potential ways to map the two fingerprints onto each other. Only the best mapping is used. Further, differences in size will also affect the final score. The larger the differences in sizes the higher the score (where a lower score indicates a better match).

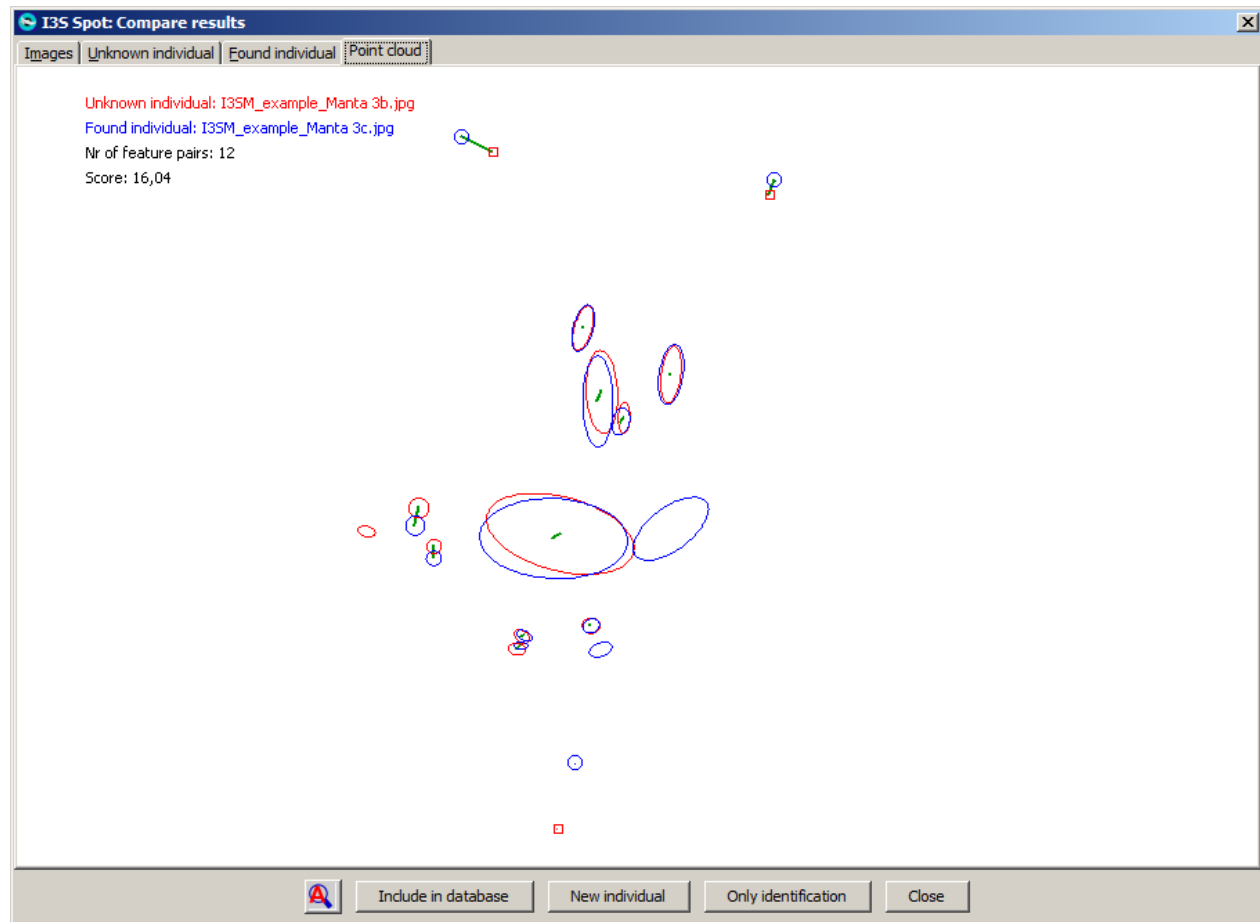


Figure 1-2: Comparison of the spots from two images.

Obviously, there are some limitations to this approach. 2D linear transformations work best for 2D linear animals, which do not exist. However, this approach has proven to be effective if some constraints are considered. For a more detailed discussion on the practical issues you are referred to Chapter 6.

For details on the original algorithm, you are referred to our paper: A computer-aided program for pattern-matching natural marks on the spotted raggedtooth shark *Carcharias taurus* (Rafinesque, 1810), A.M Van Tienhoven, J.E. den Hartog, R.A. Reijns & V.M. Peddemors, *Journal of Applied Ecology* 44, 273–280 (2007). For specific details on the implementation, please contact the I³S team by email or consult the source code delivered with the distribution.

1.3 I³S Version numbering

The version number is related to I³S Pattern. The previous version of I³S Manta was 2.1.



1.4 I³S Updates

I³S will automatically check for updates and new releases. This feature will be implemented in all I³S software packages in version 3.0 and higher. Every 30 days, upon start-up of I³S, it will check for updates. If an update is available, it will ask you if it should download and install a new version. After each update I³S will ask if you want to see the release notes on the website.

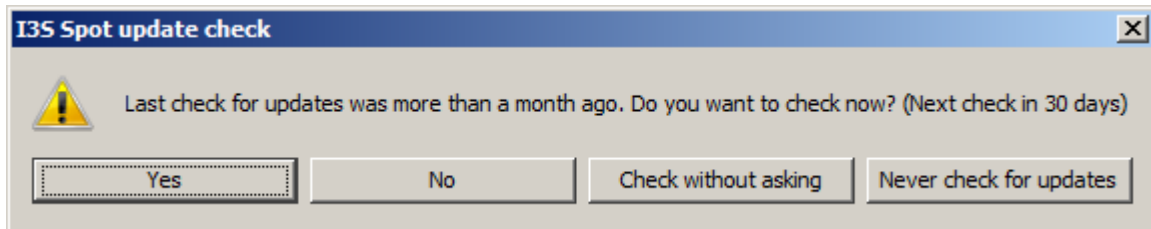


Figure 1-3: Update check.

Please note that downloading and installing updates only works in Windows Vista or Windows 7 if *User Account Control* is turned off and if you have sufficient rights. UAC prevents I³S to copy files to protected locations such as `C:\Program Files` even if you have administrator rights. You can manually set this parameter via the *Control Panel* of your computer.

1.5 What is new in this version

I³S Spot v4.0 offers significant improvements over version 2.1:

- Improved user interface showing the results. Now it is possible to view the image from the result list. With AutoZoom you directly zoom in on the area of interest. Finally, you can tell I³S to show either file names or directories in the result list.
- Accuracy of the algorithm improved on the test databases (whale sharks and ragged tooth sharks).
- Speed of the recognition improves by a factor 3 because I³S now uses the parallel processing power of your computer.
- The possibility to use and manage multiple databases.
- Easy and user-friendly definition of your own meta data structures.
- Various tools to evaluate the performance of I³S on your database and to compare two databases.
- I³S comes with the possibility of automatic updates.
- Key parameters of the recognition algorithm can be tailored for your specific data set.
- Various minor bug fixes and improvements.

1.6 Reading this document

In this document all file names, directory names and shell commands are written using the font Courier New. All names relating to a part of the I³S user interface, such as `button names` or `menu options`, are boxed. If a message is particularly important the margin will show a large red boxed exclamation mark.

1.7 Bug reports, comments and requests

Please send all bugs, comments and questions to `i3s [at] reijns.com`. In case of a bug, describe clearly how we can reproduce the bug ourselves. If possible provide us with all relevant data such as



images and fgp-files. We will always treat your data as confidential. Data will not be distributed to others without your explicit consent.

An error log file will be written in the `_ErrorLogs` directory in your data directory when internal errors are reported by the software. This file (or files) can also be sent to the I³S team along with any bug report.



2 Installation of I³S Spot

2.1 System requirements

This version of I³S requires a Windows 32-bits or 64-bits operation system (XP/Vista/Windows7). Windows 8 probably works as well, but we have not specifically tested this operating system. The software is developed using Java 1.6/1.7 and C++ (MS Visual C++ 2010). Both Java and most of the C++ code are platform independent and it should therefore be relatively simple to port it to other platforms such as Linux or Mac OS.

Hardware requirements are at least 2GB of memory (preferably 3 GB or more), and a 2 GHz CPU or faster. Increase of the identification database to hundreds of images will increase the preferred requirements on CPU speed but will have a limited impact on the memory requirements. Comparison is linear in computational requirements, i.e. an identification database with twice the number of individuals will require twice the time to compare with.

2.2 Software and data requirements

Because the main program is developed in Java, the Java Run-time Environment (JRE) is required. **This distribution will only work with a 32-bits JRE version 1.7.0 or higher!** The JRE 7 (or higher) can be downloaded for free from the Java website (<http://www.java.com/en/download/manual.jsp>) or Oracle website (<http://www.oracle.com/technetwork/java/javase/downloads/java-se-jre-7-download-432155.html>) and download version Windows x586 Offline).

Note: I³S currently only works with the 32-bits version of the JRE. I³S has been developed on a 64-bits version of Windows 7, however with a 32 bits JRE. If a 64-bit JRE is used, I³S will report an error at start-up of the program.

I³S supports both JPEG (extension .jpg) and GIF (extension .gif) images. Support of other image types is currently not foreseen as all known digital cameras can store images as JPEG.

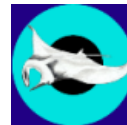
2.3 Installation

Make sure you have administrator rights and turn User Account Control (UAC) off. UAC prevents the proper installation of the Windows environment variables.

Run the file I3SSpot_v4.0_Setup.exe. If your current Java version is not sufficient you will be notified and installation terminates. It is required to install the Java Runtime Environment 1.7.0 (or higher) first.

Apart from some information about the GNU-license, the installation consists of the following steps:

1. Choosing the home directory where to install the program. Default will be in the directory C:\Program Files (x86)\I3SSPOT.
2. Choosing whether you want to store an example data directory with image and fingerprint files.
3. You can indicate if you want I³S to create a folder in the Start menu folder.
4. Finally, you can select some additional tasks:
 - a. Creating a desktop item.
 - b. Copy tutorial examples in the data directory.
 - c. Copy the source code. Only if you are interested in using or changing the source code you need to check this item.



5. If you selected to copy the tutorial images, you will be asked for the location. Please do not store the data in the C:\Program Files (x86) directory or one of its subdirectories as this may result in errors while using I³S. Choose another location such as C:\MyData.

Because an environment variable has been added you are asked if you want to restart the computer now or later. I³S will not work properly until you restart the computer or logout and login again.

If you want to install I³S under another account, this is possible. At start-up the application will search for the I3SSPOT_INSTALL environment variable which has as value the directory where I³S is installed. The default location is C:\Program Files (x86)\I3SSPOT. The installer creates this variable in the HKEY_LOCAL_MACHINE section of the registry which means that it is available for all users. If this variable is not found, the application terminates. At the first start-up by another user just select an existing database or create a new database.



Figure 2-1: Uninstall via start menu.

2.4 Uninstall

You can uninstall I³S in two simple steps:

1. Uninstall I³S, using the entry in the start menu (Figure 2-1).
2. Optionally you can also uninstall the Java Runtime Environment (JRE). In general it is not a good idea to uninstall JRE without replacing it for a newer version because other programs may depend on it. However, if you still want to uninstall JRE use the standard procedure: Select Programs and Features in the Control Panel. Then select the appropriate item from the list and click on the Add/Remove button.

2.5 Quick introduction with video tutorials

Examples are shown in our instruction videos. These video tutorials are available online at YouTube. Search in YouTube for "I3S channel". The links to these videos are also available at the website and via the [Help menu](#). Many of the videos for I³S Classic and I³S Pattern apply as well to I³S Spot. Only the annotation is different, but searching, defining metadata, etc. is identical for all versions.

2.6 Database conversion

Both database structure and fingerprint format have been changed since I³S Manta v2.1. However, this distribution comes with a simple tool which will convert your old database to the new format.

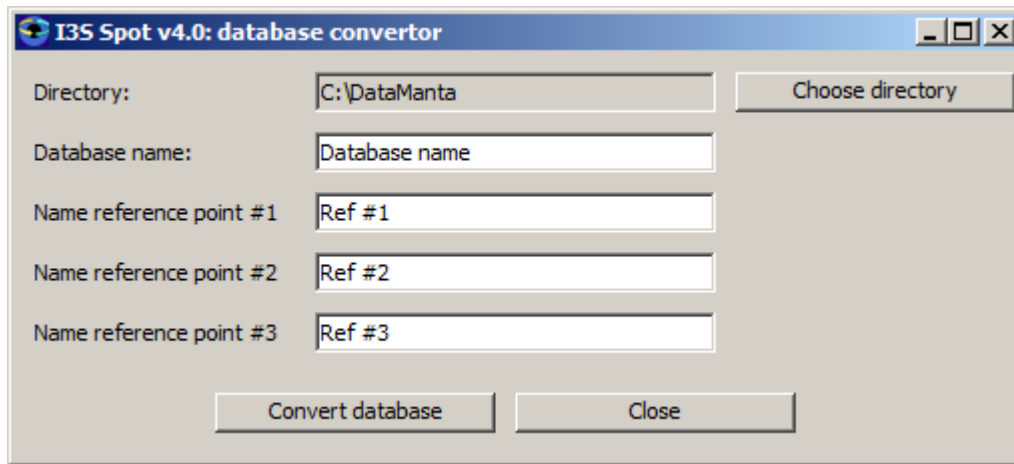


Figure 2-2: Convertor application for old I³S Manta 2.1 databases.

The figure above shows the application. The first field allows you to select the directory of the old database. By default the value will be the directory in the `I3SM_DATA` environment variable used by I³S Manta 2.1. The second field is the target directory for the converted new database. Next, you are allowed to describe the contents of the database and the names of the three reference points to be used.

When all settings are to your liking, press Convert database to start the conversion which will last seconds to minutes depending on your database size.



The convertor tool will never discard or change your existing database! It will either leave the directory unchanged or rename the directory to the current name extended with “_old”.

If you want to store the new converted database somewhere in the C:\Program Files (x86) directory you may run into problems with Windows and User Account Control (UAC). The convertor tool does not allow conversion in this case and requires you to select a location outside the C:\Program Files (x86) or C:\Program Files directories. A proper location would be C:\SpotData.



3 Data management

3.1 Introduction

I³S compares unknown images with an identification database consisting of a collection of image-fingerprint pairs. In this document, with the term 'identification database' we mean: a structured directory containing the collection of all known images used for reference by I³S. Possibly you will have another database or collection of either known or unknown images, but that is considered an entirely different database.

A fingerprint file containing all information added in the annotation process accompanies each image file. Always treat these images as an inseparable pair. If you move one of the files manually to another directory you should always move the other file along.

Earlier versions of I³S only allowed one identification database. At installation the user had to select a specific directory where the data was stored. Multiple identification databases (either other types of animals or other locations) were not supported and resulted in the need to rename and swap database directories.

I³S Spot v4.0 allows you as many identification databases you need. The locations of data directories are stored at an individual level (specific: in the registry in `HKEY_CURRENT_USER`), so it is possible to have multiple users using the same pc or laptop and manage their own databases as well as manage shared databases.

All database management is found under the menu item **Database**, see §4.1.3 for details on their use.

3.2 I³S management tools

I³S offers the following tools for data management:

1. **Search in database** Compare an annotated image against the entire identification database and show a ranked list of results. The lower the score, the better the match.
2. **Insert in database** Add an annotated image to the identification database. Either add it to an existing individual or insert it as the first image of a new individual.
3. **Reload database** In case you have manually added or removed files to the identification database directory you can reload the current database to incorporate the changes.
4. **Change database** Load another database from the list of known databases.
5. **New database** Start a new identification database and add it to the list of known databases.
6. **Rename database** Rename an existing database directory.



7. **Edit database list** Remove a directory from the list of known identification databases or add a directory. The latter is used to add an existing identification database.
8. **Edit metadata** Edit the metadata structure of the current identification database.
9. **Batch compare** If you have a large batch of new photos, e.g. collected at a field trip, and you do not want to wait for the time to compare each annotated photo against the database, this option is useful. Just put all annotated photos in a single directory and let I³S process all at once. You can read in the results and process the data later.

Further, if you want to compare two databases, e.g. to establish whether individuals migrate between locations, batch comparison allows you to find the best matches with almost no manual interaction. The results are written to an MS Excel readable `csv` file.
10. **Process batch results** Process the results in the file resulting from **batch compare**. For each compared image a search window with the results is shown.
11. **Convertor old database** Start separate application to convert an old I3S Manta 2.1 database to the new format.

3.3 The database directory

All data in an identification database is structured by means of a directory tree. Images are stored in a separate subdirectory for each individual in the identification database. Each image is described by its pattern(s) and by means of metadata fields stored in the fingerprint file with extension `.fgp`. In older versions of I³S, the sex and various views were stored by means of subdirectories under the subdirectory for the individual. Starting with v3.0, sex and views can be covered by the metadata structure. You are however required to define this yourself.

The top-level directory of an identification database contains for all known individuals a corresponding directory, the file `metadata.xml`, a directory named `_ErrorLogs` for error reports by the software, and an optional directory `_SearchResults` with the outcome of the various searches and evaluations.

For example:

Directory	Description
C:\I3S\MantaData	Top-level directory. It contains directories for the individuals Jimmy, Ronald, George and Bill and the directory <code>_ErrorLogs</code> .
C:\I3S\MantaData\Jimmy	This subdirectory contains image and fingerprint files Jimmy001.jpg, Jimmy001.fgp, Jimmy002.jpg, Jimmy002.fgp.
C:\I3S\MantaData\Ronald	This subdirectory contains image and fingerprint files Ronald.jpg, Ronald.fgp, Ronald2.jpg,



Ronald2.fgp, DSC_00261.jpg and DSC_00261.fgp.

The subdirectories for individuals should only contain image files and fingerprint files (extension .fgp). Other file types are ignored. The image files should be of type JPEG (extension .jpg or .jpeg) or GIF (extension .gif). Each fingerprint file corresponds with the identically named image file (apart from the extension). A fingerprint file contains all the spot information and extra information of the corresponding image file. The sample identification database provided with the distribution contains several individuals (i.e. subdirectories).



Do not add extra directory levels as these will not be parsed!! An example of a directory (Field trip 2013) which contents will be ignored:

C:\I3S\MantaData\Ronald\Field trip 2013\

At start-up, I³S looks up the list of known databases. In case the list contains only one, this database is loaded directly. If the list is empty, you have to create a new identification database first or select an existing database with a browser. In case the list contains more than one, you are asked to select a database from a list. After selection, the application starts to parse all the fingerprint files in the corresponding individual subdirectories. All fingerprint files are stored in memory for quick future reference during execution of search tasks. Since the fingerprint files are quite small (usually a few kilobytes) the memory use of the database will be limited.

3.4 Metadata

Each identification database has its own metadata definition. For example it is possible to define metadata fields to indicate length, size, sex, scars, or whatever you want to define for an individual. When searching the identification database, it is possible to search on the metadata as well. The exact metadata definition is stored in the file `metadata.xml` stored at the top of a database directory. It is strongly advised not to edit this file manually but to use the graphical interface provided by I³S for this purpose.

I³S currently supports four types of metadata fields: `number`, `smallmediumlarge`, `yesno` and `Custom`. The `number` format will accept any number such as 0, 12, 4.2 and -5. The type `smallmediumlarge` is a variable with three possible values (small, medium and large). Analogous, the `yesno` type is a Boolean variable with values yes or no. `Custom` lets you define a discrete and limited set of values yourself.

3.5 Error checking on the database

If you manually change the database, e.g. by moving around files or directories, you might introduce errors. I³S will check for some errors when parsing the database. The checks performed by I³S are:

1. Does each fingerprint file have a corresponding image file in the same directory? This error typically occurs if you move the image file but forget the fingerprint file or vice versa.
2. Are there subdirectories within individual directories? A warning is generated that the contents of these directories are not parsed.

If there are errors found a pop-up window is generated. A description of all problems found is written to the file `db_errors.txt` in the `_ErrorLogs` directory of the database.



4 The I³S user interface

This chapter will address the possibilities of the I³S user interface. First, the menu bar and toolbar are described. Next, the interaction with the annotation panel is discussed.

4.1 The menu bar

I³S offers a standard Windows look & feel menu-based interface to perform most operations. In the paragraphs below, the six menu items will be explained. An overview of the title and menu bar is shown in Figure 4-1. The title shows the application name version and some details about the database: name, type and between brackets the number of fingerprints and individuals in the database.

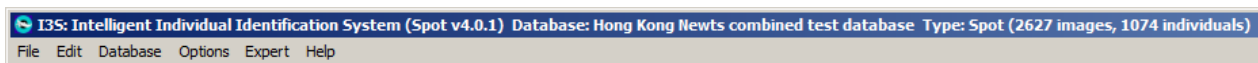


Figure 4-1: The I³S menu bar.

4.1.1 The File menu

This is the main I³S menu. Figure 4-2 shows the various operations, which are discussed below:

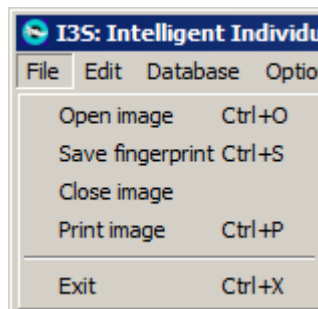


Figure 4-2: the file menu.

- **Open image** (shortcut **CTRL+O**). It will open a window to choose an image file. The supported image types are JPEG and GIF. The starting directory will be the top level directory of the selected database. If an image file has a corresponding fingerprint file (i.e. the same name but extension `.fgp`) a manta logo is shown, a standard image logo otherwise. The logos are shown below:



- **Save fingerprint** (shortcut **CTRL+S**). If you have annotated an image this operation will write a fingerprint file in the same directory as the corresponding image together with any metadata. Apart from the extension, which is `.fgp`, the name will be identical to the name of the image file.
- **Close image**. It closes the image in the main window. If you have unsaved data I³S will prompt you whether you want to save the data first.
- **Print image** (shortcut **CTRL+P**). It will print the current image including comments (see §4.2).



- **Exit** (shortcut **CTRL+X**). This operation will close all windows. In case of unsaved data I³S will prompt you whether you want to save the data first.

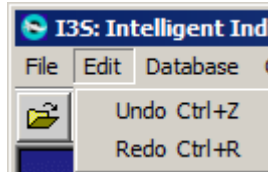


Figure 4-3: The edit menu.

4.1.2 The Edit Menu

- **Undo** and **Redo** are completely analogous to standard Windows functionality. The last 500 edit actions are kept in memory (Shortcuts: **CTRL+Z** and **CTRL+R**).

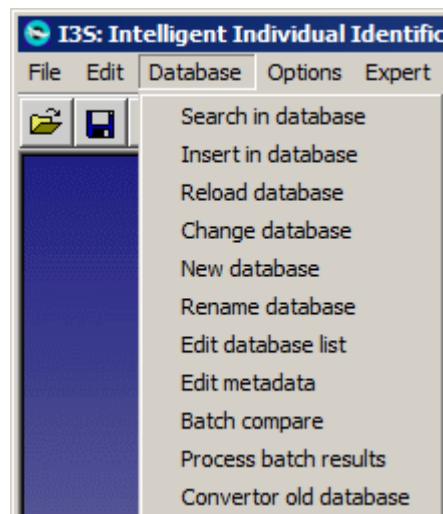


Figure 4-4: The database menu.

4.1.3 The Database menu

- **Search in database** will compare the current image with the rest of the identification database. See Chapter 0 for details.
- **Insert in database** In case of a loaded and annotated image, selecting this operation will allow you to add a new animal (i.e. a new subdirectory) to the identification database. This operation pops up a new window first that will prompt you for the name of the new animal. Selection of the checkbox **Rename file** will allow you to change the name of the image. By pressing **OK** the image and its fingerprint file are copied (not moved) to the appropriate directory in the identification database. The figure below shows an example. If the file has been renamed, you are asked whether the original file needs to be renamed as well.

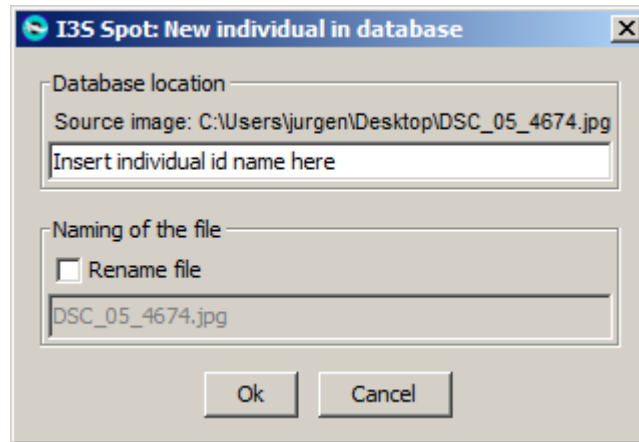


Figure 4-5: Insertion in the identification database.

- **Reload database** If the identification database has been changed, i.e. fingerprint files have been manually added or removed using e.g. Windows explorer, this operation will reload the entire database. You do not have to call this operation after insertion of a new animal in the identification database. In this case, I³S will reload the database automatically.

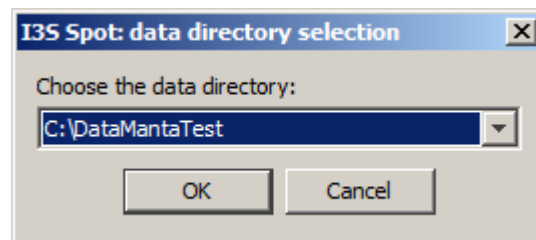


Figure 4-6: Changing the database.

- **Change database** If you have multiple identification databases it is possible to load another identification database without exiting the application. This menu option will offer you a list to choose the database. Choosing the current database is identical to **Reload database**. Before changing the database, open files are closed and/or you are asked whether to save first.
- **New database** If you want to create a new identification database choose this menu option. First, you are asked to select a **new** directory, either by typing it in at the text field **Folder name** or selecting the **Create new folder** button. Figure 4-7 shows the window. When you nevertheless choose an existing directory, the application will ask to create a new directory within the chosen one. After selecting a new directory, you are offered the window shown in Figure 4-8. Use this window to specify the database name. Type in a concise name as it is also shown in the top of the main application window. You can also change the description of the reference points. Further, it is possible to add a number of metadata fields to the identification database.
- **Rename database** This option allows you to rename the directory of an existing database. First, you are asked to select an existing database, and then to type in the new name. Only letters, digits and spaces are allowed. After renaming, you are asked whether you want to change to this database.

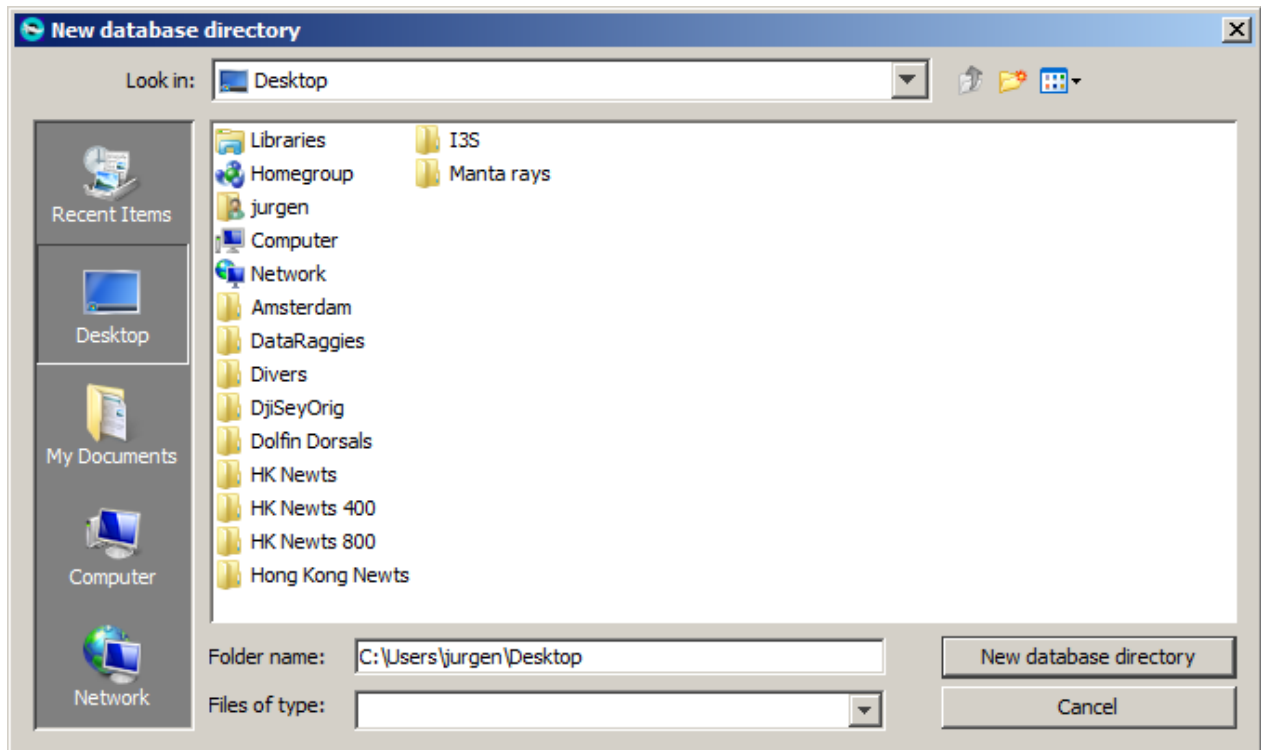


Figure 4-7: The first step in creating a new database, directory selection.

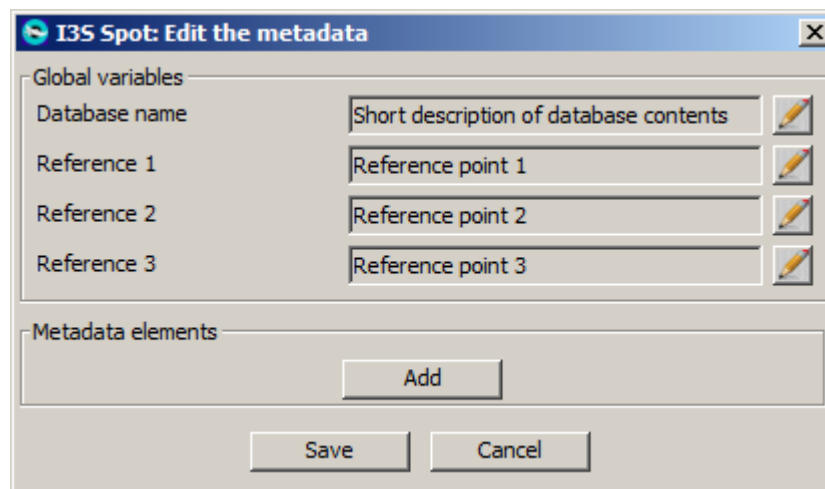


Figure 4-8: Setting-up the database (non-expert mode).

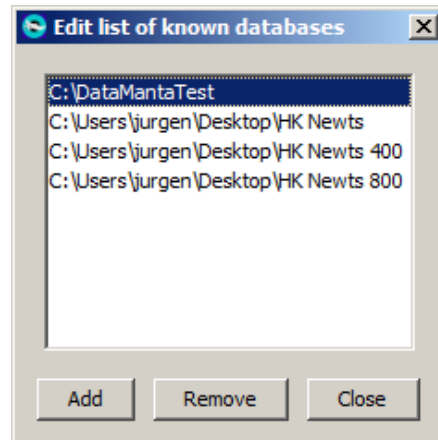


Figure 4-9: The window to edit the database list.

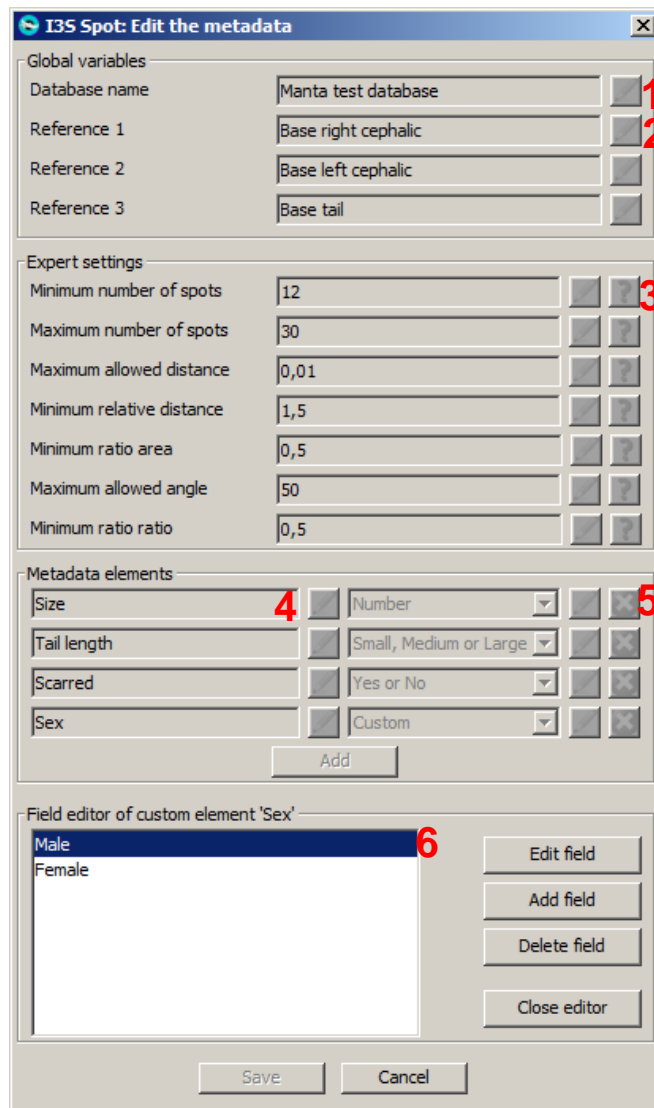







Figure 4-10: The window to edit the metadata (expert mode).



- **Edit database list** If you want to remove an old database from the list of known databases or add an existing database directory you can use this option. Figure 4-9 shows the corresponding window. **Remove** deletes the selected directory from the list but it leaves the files in the map untouched. **Add** lets you select an existing directory and adds it to the list without checking whether it is a valid identification database directory (this will happen when the database is actually loaded).
- **Edit metadata** This option allows to edit the metadata fields for the current database. Figure 4-10 shows the window.

The red numbers 1 to 6 indicate some important aspects of this window:

1. The field database name defines the name which is shown in the title of the application. Press the button  to alter the name. When editing a field, it is not possible to select other buttons, except **Cancel** or  again to save the result.
 2. Names of the three reference points.
 3. The expert settings are only available in “expert mode” (see also paragraph 4.1.5). The  will show a pop-up window explaining each variable. These variables are used for fine tuning the recognition algorithm. You are also referred to paragraph 6.6.
 4. Use the left column of buttons to edit the names of the metadata elements.
 5. Press the button  to remove the field.
 6. Press the button  to edit the names of the custom field type. This button is only available for type custom as only this type allows you to define a list of possible values, as is shown for type ‘sex’. When pressing this button the window is enlarged to show the fields to edit the possible values as shown above. All other elements are greyed out, except for **Cancel** and the buttons to edit the fields for the custom element. The minimum number of values must be two, the maximum is limited to 10. **Close editor** stores the list of values (if valid) and returns the window to the previous state.
- **Batch compare**. With this option you can compare a directory with annotated images directly with the identification database. This feature might be useful if you have a large batch of new photos, e.g. collected at a field trip, and you do not want to wait for the time to compare each annotated photo against the database. Another application is to compare two databases to determine whether there is overlap in individuals to establish migration patterns.

The results are written to an MS Excel readable `csv` file in the `SearchResults` directory of the current reference database. After selecting **Batch compare** the window shown in Figure 4-11 pops up. Choose the directory with your annotated new data and I³S will start with comparing each photo against the database. A progress bar keeps track about the time still required. After finalization a message is shown where the data is written. Use the options menu to specify how many of the best matching results are written to the batch results file.

- **Process batch results**. This menu item allows you to process the results from the batch compare. Each compared image pops-up together with a standard search result window (paragraph 5.2).
- **Convertor old database**. Start separate application to convert an old I³S Manta 2.1 database to the new format. See paragraph 0 for more details.

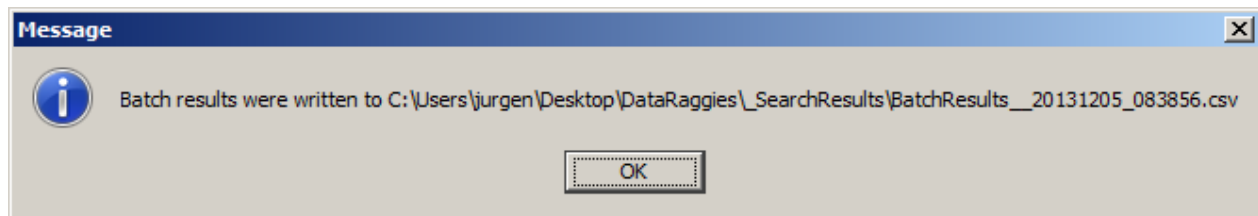
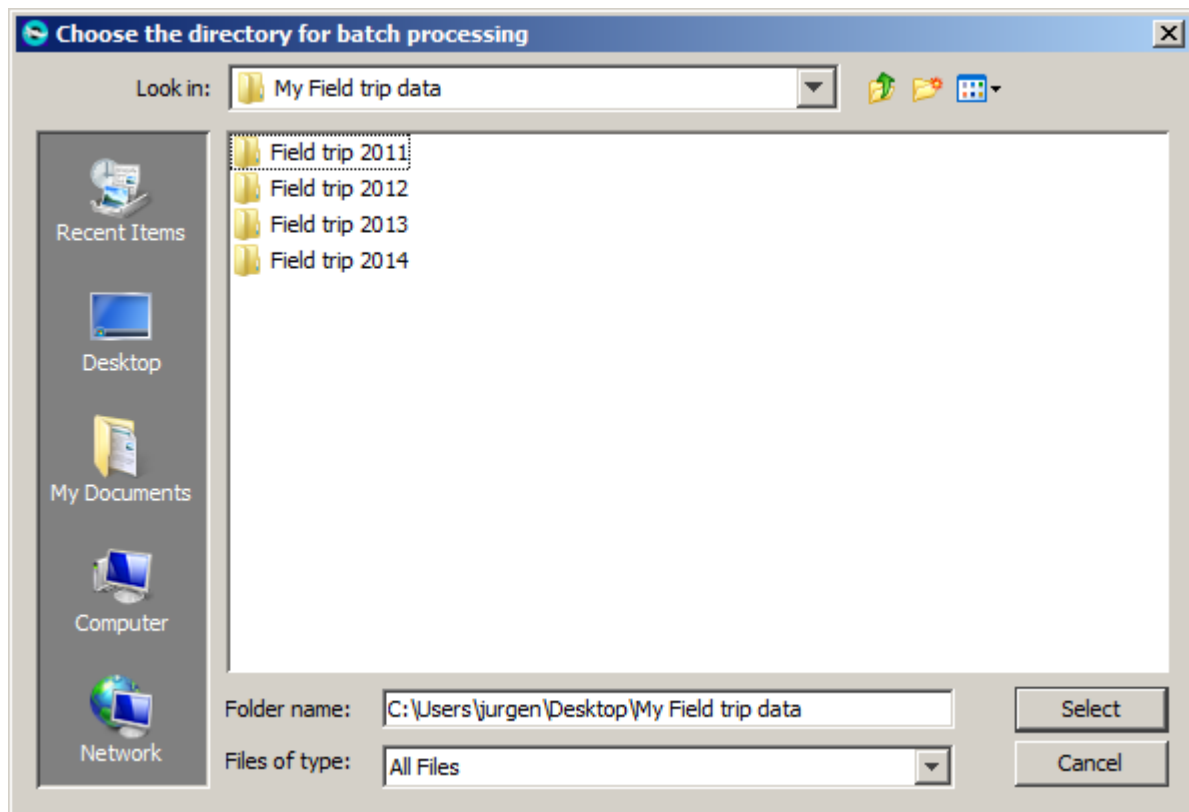


Figure 4-11: The window to choose the batch directory (top) and the message confirming the export of all results to the csv file.

4.1.4 The Tools menu → Option results

Options results will pop-up the left window shown in Figure 4-12.

The first part **Logging results** of the left options window concerns the automated logging of the searches performed. If logging is on, the outcome of each search will be written to a file in the database directory (subdirectory `_SearchResults`).

The naming of the file is `SearchResults__<date>_<time>.log`. For example, a search on the second of July 2013, at the time of 17:22:10 will be written to the file named `SearchResults__20130702_172210.log`. The content of the log file is identical to the results in the search results window. Each line contains a filename and the score separated by tabs. Excel can process this format.

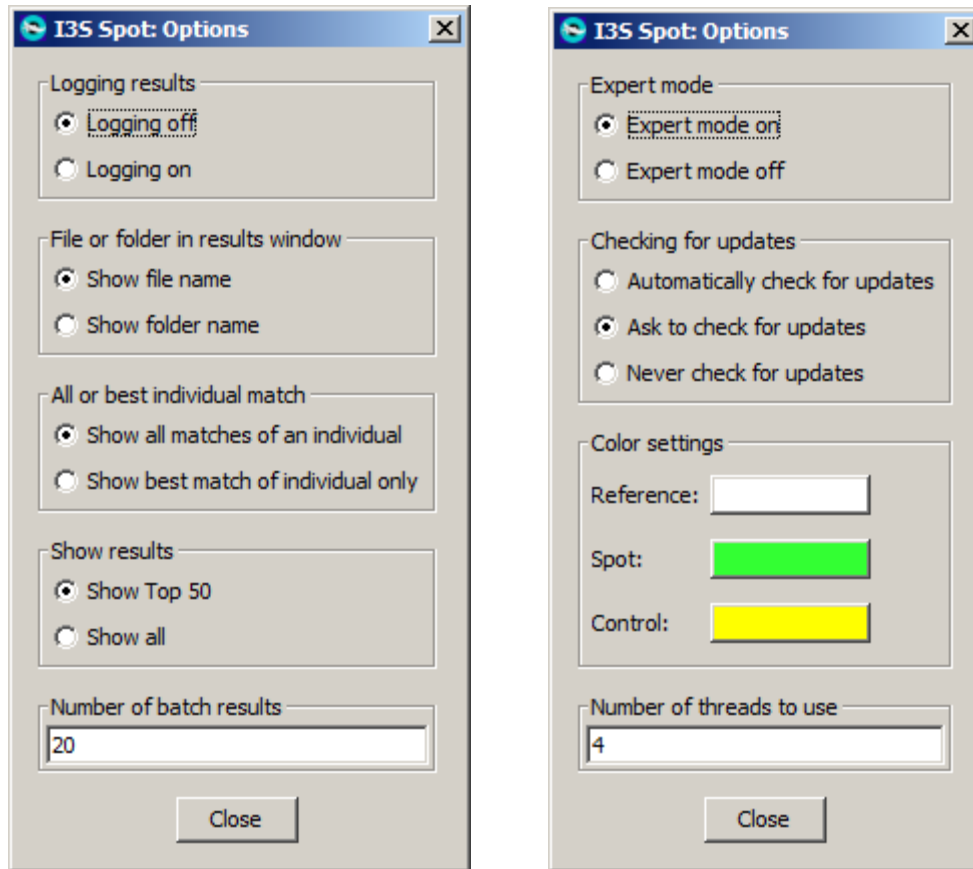


Figure 4-12: The two option windows.

The second part **File or folder in results window** will determine whether the results window will show the last directory of a matching file, or the filename itself. If you choose the filename, please make sure each filename identifies the individual by name or code.

The third part **All or best individual match** is used to choose between showing all matching files in the database or just only the best file from an individual directory.

The fourth part **Show results** can be used to indicate whether you are interested in the top 50 of best matches or the entire identification database. This choice will affect both the logging and the search results window.

Finally, **Number of batch results** determines how many matches are shown when batch processing. For example, each time an unknown fingerprint from the batch directory is compared against the database only the top number of matches is stored.

4.1.5 The Tools menu → Options general

Options general will pop-up the right window shown in Figure 4-12.

The first part determines whether I³S is in expert mode or not. When in expert mode, the expert menu is shown, while editing the metadata shows more options.



The second part allows you to choose the interaction with respect to updates. When choosing **Automatically check for updates** the software will check periodically without interaction. Only when an update is found you will be asked whether you want to install. **Ask to check for updates** will make sure I³S gets permission before an update check. **Never check for updates** will make sure I³S never bothers you about updates, unless you manually choose **Check for updates** from the help menu.

The third part named **Color settings** allows you to select which colors to use for the annotation elements. This can be particularly helpful if the species under study happens to show colors similar to the default colors used or if you are color blind.

The final part named **Number of threads to use** determines how much I³S may use of the parallel processing capabilities of your computer. Default is 1 thread. If you increase this number, recognition speed will increase as well, however, other tasks carried out in parallel may also become slower (e.g. word processing, Excel, etc.). Experiments indicate a maximum speed-up of 3 compared to a single thread (see §6.2 for details). Any time you can set this level to the desired value.

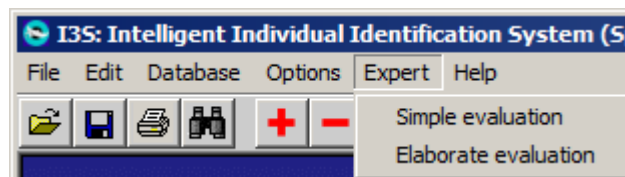


Figure 4-13: The expert menu.

4.1.6 The expert menu

This menu item is only available when expert mode is chosen with the **Options general** menu under Tools. See also the previous paragraph. This menu offers two evaluation options: simple and elaborate evaluation.



If you have multiple regions of interest per individual, e.g. left and right side photos of the same individual, make sure to put them in different directories before doing the evaluation. For example, make two different directories for Turtle73: Turtle73_Left and Turtle73_Right. Otherwise, the evaluation tool will count mismatches between right side photos and left side photos incorrectly as errors (the evaluation tool does not consider the metadata).

Simple evaluation

This option is used to get an indication how good the various instances of the same individual match with each other, and whether I³S can be used for matching a certain species. All fingerprints in the database are compared with all other fingerprints. If a match between two instances of the same individual yields a score outside the top 10 of best matches this is logged. After the entire database is matched with itself, an overview is produced which may look like this:

Simple evaluation results	
# intra individual comparisons: 210	The number of comparisons between fingerprints of the same individual. For example, in a database with 10 individuals and 3 annotated photos per individual, this number will be 60 as each of the 30 fingerprint has two



	possible matches.
Accumulated ranking score: 1218	For each comparison between two fingerprints of the same individual, the found ranking is added to a total. If the match between two such fingerprints results in a 15h place in the total ranking, the total is increased with 15.
Best possible (ideal) score: 273	This is the best score theoretically possible. In the database with 10 individuals and three fingerprints per individual, each of the 30 fingerprints ideally has its two other sibling fingerprints ranked 1 and 2. In this case, the ideal score would be $30 \times 1 + 30 \times 2 = 90$.
Evaluation took 13 seconds (3,98 msec per comparison, 3306 comparisons).	Some statistics about the total number of comparisons and the time required.
Top #1: 133 (63,33%)	The top #X defines the number and percentage of comparisons resulting in a ranking in the top X of results.
Top #2: 174 (82,86%)	
Top #3: 186 (88,57%)	
Top #5: 189 (90,00%)	
Top #10: 195 (92,86%)	
Top #20: 199 (94,76%)	

The results of the evaluation are written to a file in the database directory (subdirectory `_SearchResults`). The naming of the file is `EvaluationResults__<date>_<time>.log`.

Elaborate evaluation

Elaborate evaluation simulates a realistic scenario. After selecting this menu option, the window in Figure 4-14 is shown. The user can select the number of iterations and the number of reference images. Next, I³S basically separates the database in a reference set and a test set. From each individual directory, the specified number of reference images is randomly selected and added to the reference set. All remaining images are added to the test set. Next, each test image is compared against the reference set. Statistics are kept about the number of times the right reference image shows up in the top 1, 2, 3, 5, 10 and 20.

The output may look like:

```
Elaborate evaluation results
1000 repetitions, 3 reference images. #refs: 447 #test: 292

Expert settings   MaxAllowedDist: 0.01   MinRelDist: 1.5
Filling the matrix: 3172 seconds
Random iterations: 1031 seconds

Top #1: 266731 (91,35%)
Top #2: 276891 (94,83%)
Top #3: 279618 (95,76%)
Top #5: 281719 (96,48%)
Top #10: 284117 (97,30%)
Top #20: 285706 (97,84%)
```



On this specific database of 739 images, using 3 reference images per individual, gives 95,76% probability that when comparing a new image of an individual already in the database, the proper individual is found in the top 3.

More reference images will in general yield better results. However, more reference images will make the set of remaining test images smaller, which could result in less significant experimental results.

Because the distinction between reference and test images is based on random selection, you need to repeat the process a lot of times to average out any random effects. The iteration parameter determines the number the process is repeated. The default value is 100. A 1000 iterations will require more time, but because of a pre-processing step, 1000 iterations will require relatively little more than the time needed for 100 iterations.

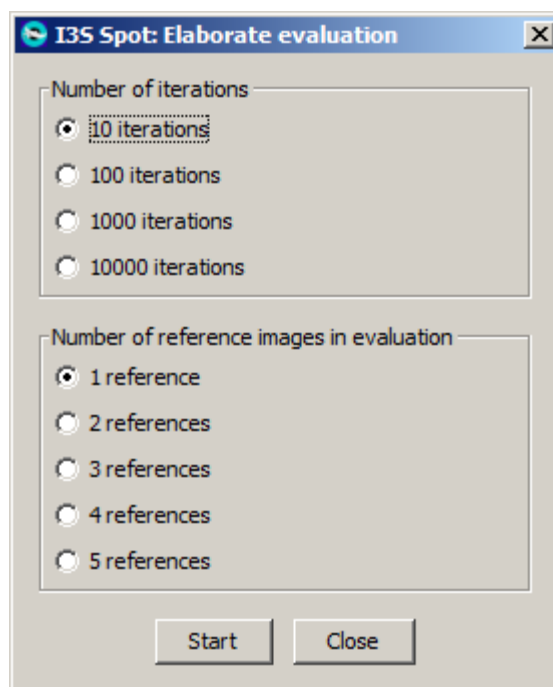


Figure 4-14: Elaborate evaluation window.

Evaluation of the database may be very time consuming. A good indication of the time required is the time needed for a single comparison against the entire database x the number of fingerprints in the database. During processing you can change the amount of CPU power used by the evaluation process by adjusting the slider towards 'slow' or 'fast'. Faster evaluation might make other applications less responsive.

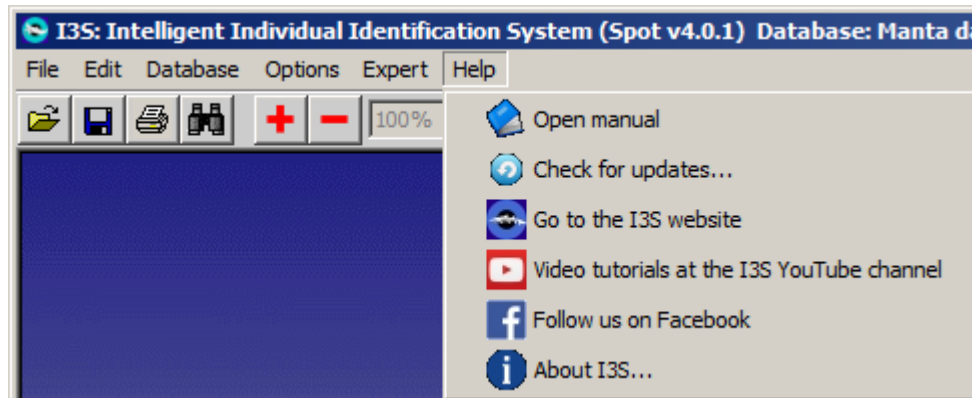


Figure 4-15: The Help menu.

4.1.7 The Help menu

- **Open manual** will start your default PDF reader and open this manual.
- **Check for updates...** will check if there are updates. If an update is available you will be asked only once to install at the next start-up of I³S, even if update checking is disabled. For successful installation Windows User Account Control has to be turned off.
- **Go to the I3S website** will open your default web browser and show the I³S website.
- **Video tutorials at the I3S YouTube channel** will open your default web browser and show the start page of the I3S channel at YouTube.
- **Follow us on Facebook** will open your default web browser and show the Facebook page of I3S.
- **About I3S...** shows a window with information on version number, authors, copyright, acknowledgements and contact details.

4.2 The tool bar

Below the menu bar I³S shows a tool bar, which offers short cuts to functions described in the previous paragraphs and some new functions. An overview of the tool bar is shown in Figure 4-16.

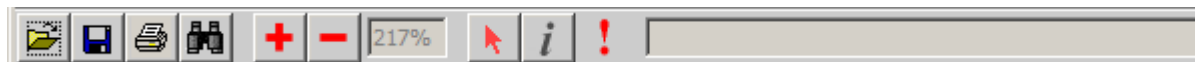


Figure 4-16: The tool bar.

The table below describes the various items in detail.

	Open file. Button for the menu option described in §4.1.1.
	Save file. Button for the menu option described in §4.1.1.
	Print file. Button for the menu option described in §4.1.1.



	Search. Button for database search described in Chapter 5. A keyboard shortcut is ALT+S .
	Controls for zoom. Pressing the plus will zoom in on the image. If the enlarged image does not fit the screen two sliders will appear. The mouse wheel can also be used for zooming. The minus will zoom out. The zoom factor is displayed right of the minus. The maximum allowed zoom factor is 1000%.
	Activate or de-activate edit mode. If yellow, editing is activated. If grey it is not active.
	Edit the information field. Each fingerprint file contains an information field. Upon pressing the button, a metadata editor is opened (see §5.1 for details). If the button is grey you need to activate the edit mode first.
	Change indicator. If the annotation has changed the button becomes yellow until the fingerprint is saved.
	A field, which will show instructions or the number of spots during annotation. The field is larger in the application. If a message is shown, the field will be yellow.

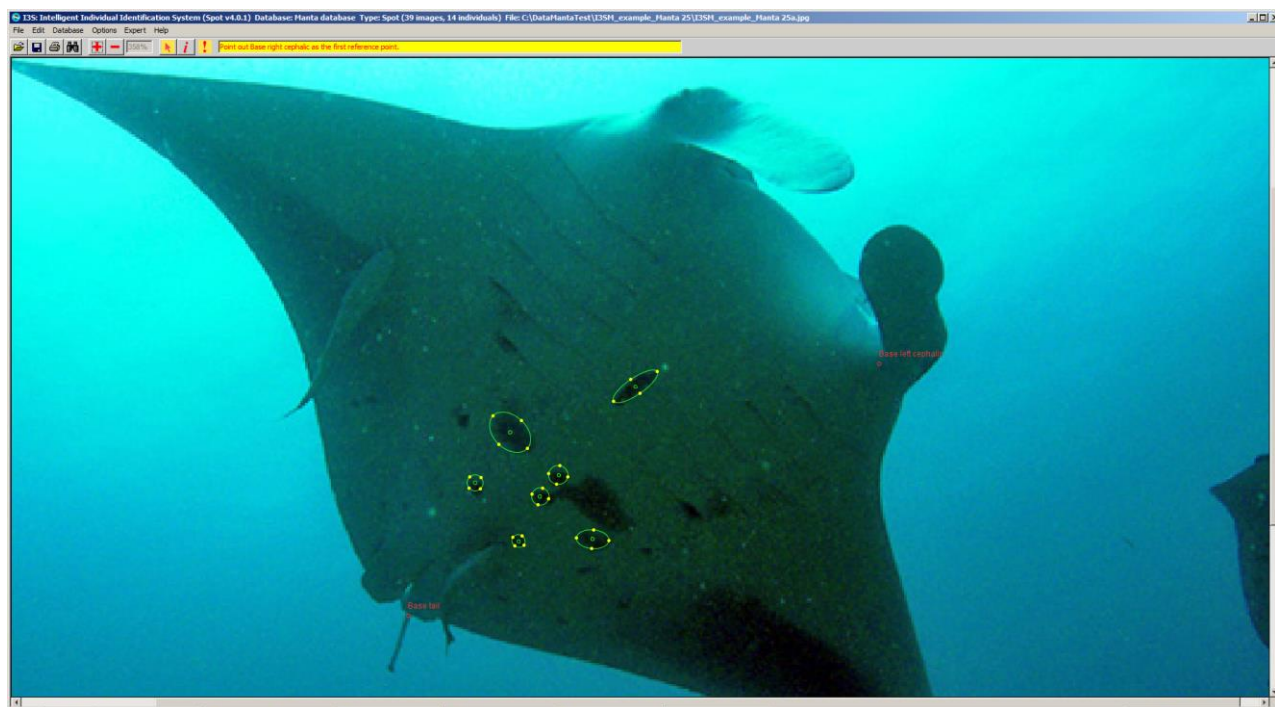


Figure 4-17: Annotation of the first reference point with instructions in the yellow text field. (Image source: Manta Trust)


4.3 Spot annotation

An important part of the user interface is focused on spot annotation. Below the annotation process is discussed in the two steps during annotation: reference points annotation and spot annotation.



The annotation process starts with loading an image and putting I³S in edit mode, both were described earlier in this manual.

4.3.1 The reference points

For the algorithm it is essential to have a first indication how two images roughly match. For this step the reference points are used. If the reference points are not annotated, I³S requires you to annotate these first. Before you start, activate edit mode first ().

The reference points are annotated by clicking with the left mouse button the three reference points in a fixed order. Do not mix-up these reference points as this will obstruct proper recognition! If you click a wrong position you can undo this by clicking with the middle or right mouse button. The text field will show in bright yellow which reference point to annotate. In the example in Figure 4-17 the text field shows “Point out Base of right cephalic as the first reference point”.

You are entirely free to choose your own reference points. Give them proper names which make sense and which are not easy to mistake for each other (names like ref1, ref2 and ref3 are not a good idea). Further, the reference points should be clearly visible in all images and in an ideal case they should form a triangle with 60 degree angles.

For manta rays, we chose the following reference points:

1. Base of the right cephalic fin.
2. Base of the left cephalic fin.
3. Base of the tail.

4.3.2 The spots

After annotation of the reference points you can start with the spots. Click on the image and drag the mouse while keeping the left button pressed along the image. A circle appears along the path you drag. Each circle has 4 control points and a center point. You can manipulate the ellipse by dragging one of the control points or its center. Keep the control button pressed and click on one of these control points while keeping the left mouse button pressed. If you drag the mouse, the selected control point will come along. In case you selected the center point, the entire ellipse will move. If you selected one of the four control points the shape of the ellipse will change (Figure 4-18).

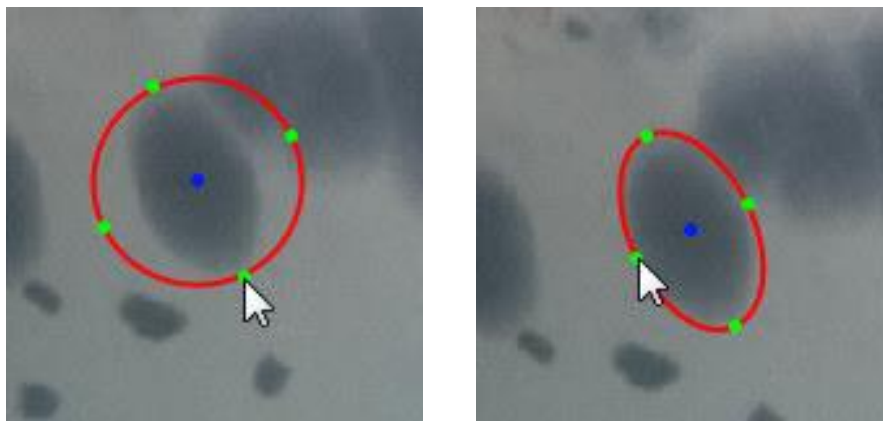


Figure 4-18: Annotation in two steps. First dragging a circle (left). Secondly, adjusting the ellipse to fit the spot (right).



You can always undo an edit action (or multiple edit actions) by pressing **CTRL-Z**. You can redo one or more edit actions by pressing **CTRL-R**. Select an ellipse by clicking on its center while pressing **CTRL**. By pressing **CTRL** and one of the arrow keys you can move the selected ellipse a small step in the corresponding direction. By clicking with the middle or right mouse button near the center of a spot, the entire spot will be removed.

Please be as accurate and consistent as possible in your annotation. Just because recognition is a partly automatic process, this does not mean that the human input is not vital. Any computer program, and I³S is not an exception, works according to the principle of “*garbage in → garbage out*”.


You are also referred to the relevant tutorial on the I³S YouTube channel.



5 Searching and using metadata

This chapter discusses the search process in more detail. First, the options to add metadata are discussed. Next, the search process is described in detail.

5.1 Adding metadata

I³S allows you to add metadata to an image. Metadata is additional information, which describes the individual, location or perhaps the conditions in which the image was taken. If you press the  button in the toolbar a new window pops up. The window is shown in Figure 5-1 with a fictive example.

The upper text field allows you to store plain text. There is no limitation to its length. If no text has been added yet, 'Empty comment field' is shown.

The **Metadata elements** field below allows for a more structured input. Four types of fields are available: numeric, general size with three possible values (small, medium, large), Boolean (yes/no) and custom. The latter is a finite user-defined set of values. The window below shows an example of each type. The numeric field expects a number using the keyboard. Selecting a value from the dropdown menu sets the other types. I³S allows you to include metadata elements in the search process described below.

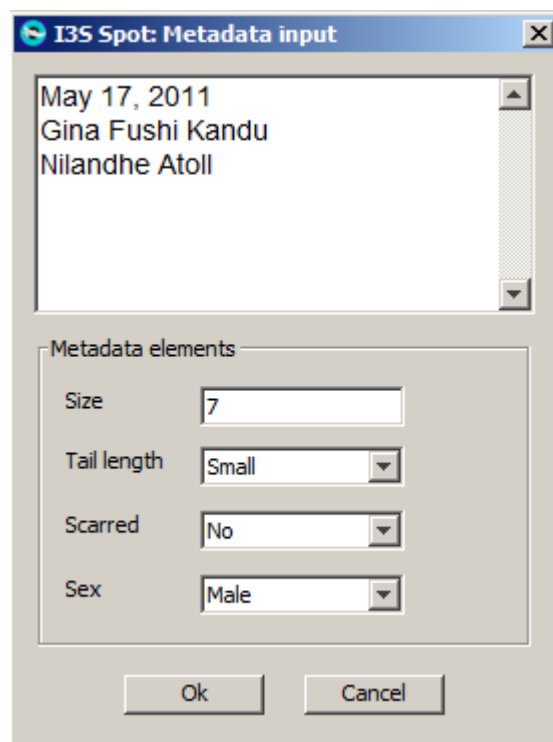



Figure 5-1: The metadata window.

The metadata fields are not fixed and can easily be edited by the user. The metadata structure is defined in the file `metadata.xml` in the database directory but I³S provides a tool to edit the metadata. For more information you are referred to §4.1.3.



5.2 The search process

After selecting **Search in database** from the **Database menu** or pressing the search button , a new window will appear as shown in Figure 5-2.

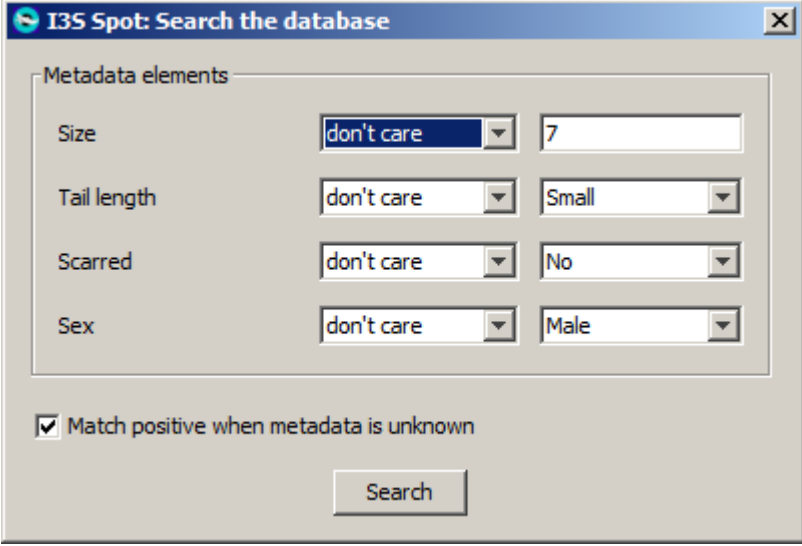


Figure 5-2: Default search window.

By default all defined metadata elements are set to “don’t care”. You can also indicate how the search process should act if an individual does not have a specific metadata element defined. By default, the search will not fail on missing metadata.

If the **search** button is pressed, the current annotated photo will be compared against the entire database without considering the metadata elements in the fingerprints. If the search takes more than a second, a progress bar is shown.

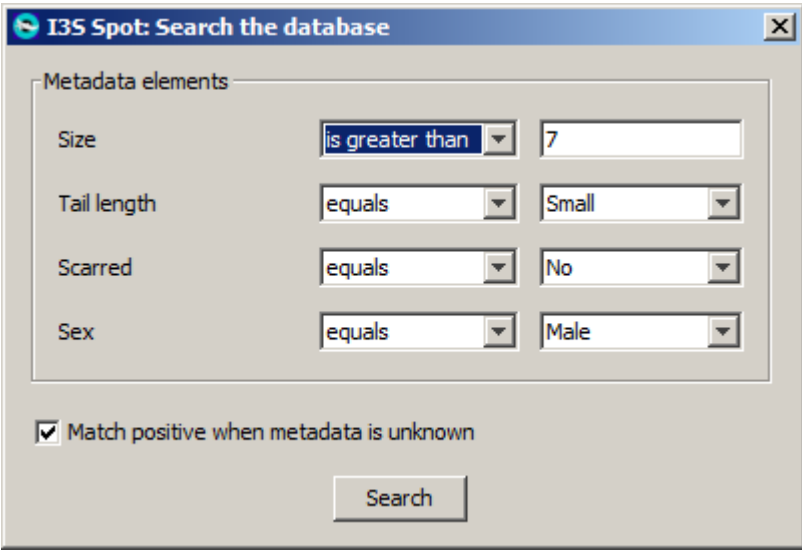


Figure 5-3: Search window with metadata criteria.



You can also search on specific metadata. The metadata structure is defined for the entire database in the file `metadata.xml` in the top of the database directory. You can select per type of field the appropriate constraints (e.g. `equals`, `is less than`, `is greater than` or `don't care`). If you select the default `don't care`, that field will not affect the search process. If one or more metadata elements do not satisfy the search constraints, the specific image is put at the end of the list of search results. If a metadata element is not available (i.e. not yet annotated) the search process will ignore this specific element and not exclude the image if you select “Match positive when metadata is unknown”

Figure 5-3 shows the search window with specific constraints set for the metadata elements. In this case, the search will only consider fingerprints with a size greater than 7, with sex ‘male’ or unknown, tail length equal to “Small” or unknown, and not scarred or Unknown.

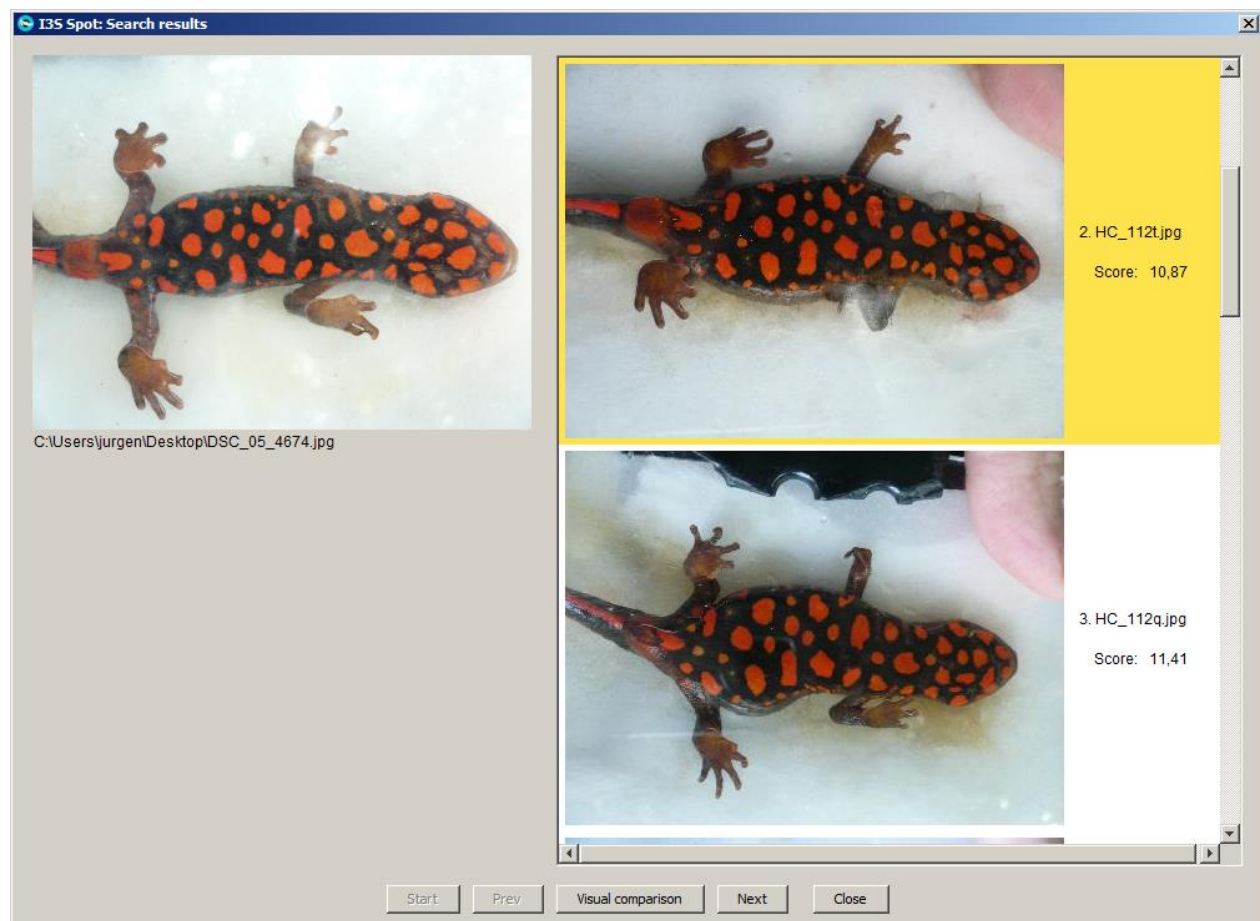


Figure 5-4: Search result window (Image source: The University of Hong Kong).

When you click `Search` the Search result window shown in Figure 5-4 appears. Top left shows the unknown individual. The right side of the window shows the ranked list of photos from the database, 10 at a time. With the vertical scroll bar you can scroll along the current set of 10. When the window opens, the best ranked photos 1 to 10 are shown. The buttons `Prev`, `Next` and `Start` allow you to go to the previous set of 10, next set of 10, or the first best 10. If currently matches 1 to 10 are shown, next will show 11 through 20.

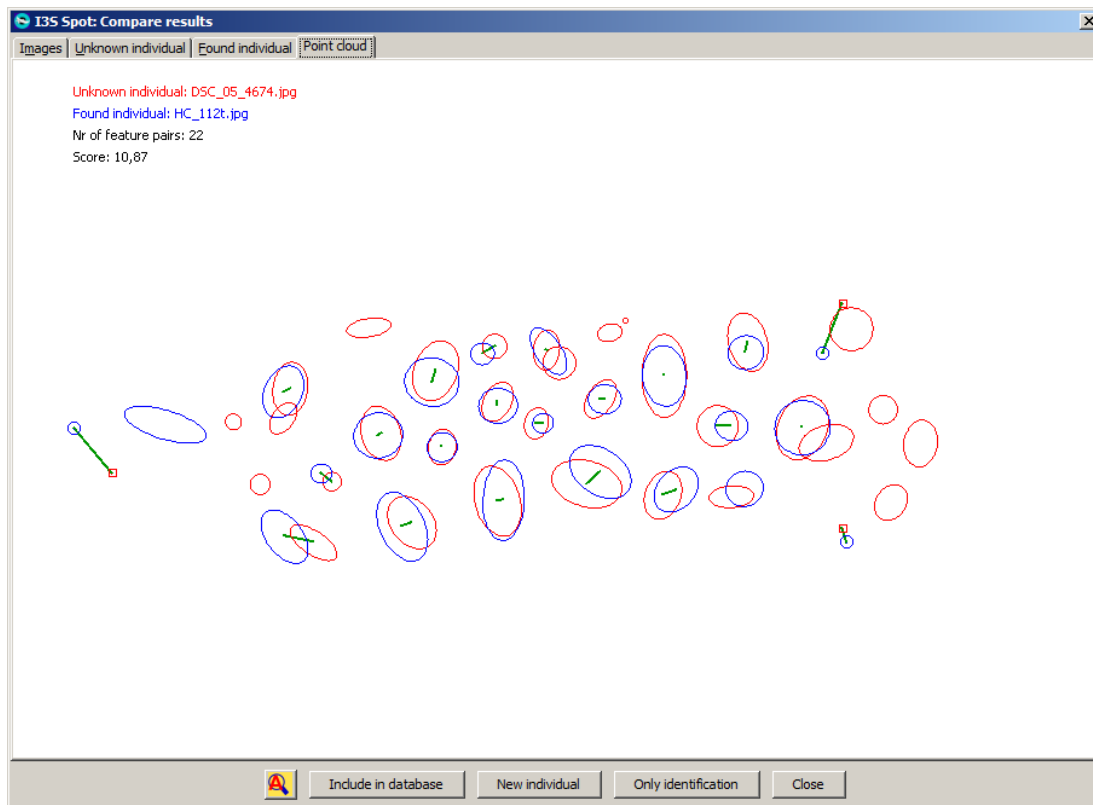


Figure 5-5: Image and spot cloud (Image source: The University of Hong Kong).



By clicking one of the results in the list, the item turns yellow and the button **Visual comparison** becomes clickable. When clicking it, a new window named “Compare results” will appear as shown in Figure 5-5. The window contains four tab panes. The first shows both images together with the annotated pattern and comments. The second and third tab pane shows the image of the unknown animal and the selected animal from the results list respectively. The fourth tab shows the normalized patterns in the same recognition space where the known fingerprint is transformed optimally to have the best fit with the unknown fingerprint.

The first pane is equipped with a built-in magnifying glass. When you move the cursor over one of the images the magnified part is shown to the right. Click with the left mouse button in the image to lock or unlock the magnifying glass. When locked the symbol of a yellow lock is shown. Locking the magnifying glass allows to compare two parts of the image in detail. By scrolling with the mouse wheel you can change the amount of magnification.


The button  indicates whether AutoZoom is on or off. When yellow, AutoZoom is on. When ‘on’ the visual comparison window will zoom in on the identification area. Figure 5-6 shows the difference.



Figure 5-6: With and without AutoZoom (Image source: University of Hong Kong).

5.3 Actions after the search is completed

Based on the information in the ‘Compare results’ window you will ultimately decide whether the individual is already known or unknown. You have four options how to proceed and four corresponding buttons at the bottom of the window:

1. The individual is known and because the image is of good quality you want to add it to the identification database as reference in future searches Press **Include in database**.
2. The individual is new and you want to add it to the identification database in a new individual directory. Use the button **New individual**.
3. The individual is recognized but you do not want to add it to the identification database. You only want to rename the image at the current location, e.g. in your own database. Use the button **Only identification**.
4. You do not want to undertake any action. Press **Close**.

Figure 5-7 shows these buttons in more detail.

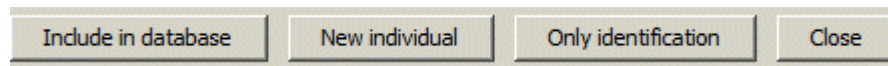


Figure 5-7: The four other buttons at the bottom of the visual comparison window.

5.3.1 *Include in database*

Only add good quality images to the identification database. Poor quality images (e.g. large deviations from a perpendicular viewing angle with respect to the animal) will lead to poor quality search results. Ideally, aim at having about three reference images per individual in the identification database. When clicking on the 'Include in database' button the following window will appear.

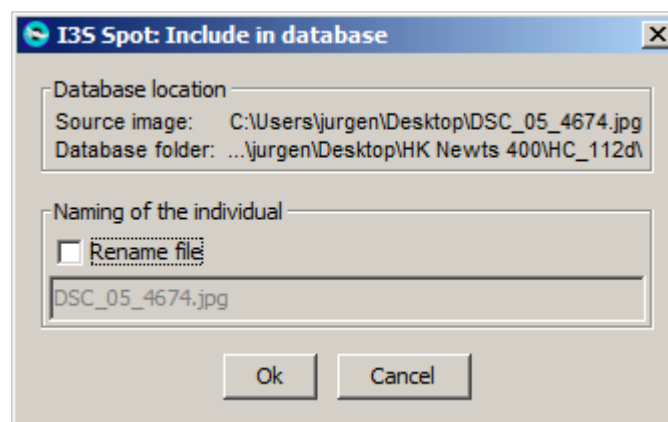


Figure 5-8: The 'Include in database' window.

By clicking the field Rename file you can also edit the filename. The fingerprint file will get the same name, only with extension .fgp. We strongly advise to make sure that each filename contains the identification number or name of the individual. After clicking OK both the image and the fingerprint file are copied (not moved) to the same directory as the matching image you selected. If you have renamed the file, you will be asked whether you want to rename the original file as well.

5.3.2 *New individual*

If no matching individual was found you will probably assume it is not yet in the identification database. To add it to the database, click on the appropriate button. The following window will appear.

Fill in the name of the individual. This can be a name like 'Gregory' or just a number such as 'Newt 112'. This name will be the name of the new directory. In the next section you can choose to rename the image and fingerprint file. We strongly advise to rename the file so it represents the identity. For example, in case of Gregory you could name the file Gregory-12March2009Yap.jpg. After clicking OK both the image and the fingerprint file are copied (not moved) to the new directory in your identification database you just specified. If you have renamed the file (which you should have), you will be asked whether you want to rename the original file as well.

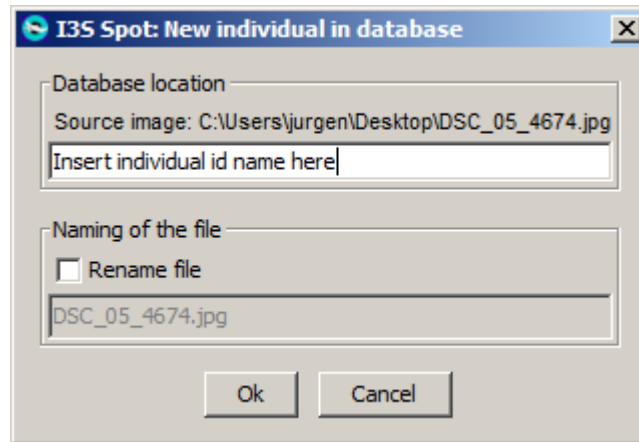


Figure 5-9: The 'New individual in database' window.

5.3.3 *Only identification*

If you have successfully identified an individual but do not want to include the image in the identification database, you still might want to rename the file. In this case, press **Only identification** and the following window will appear.

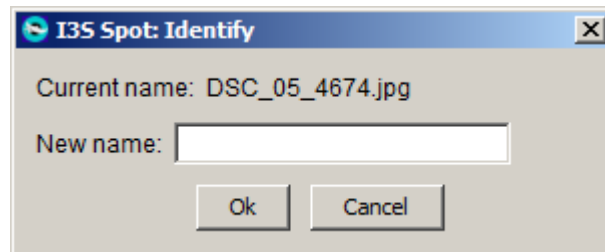


Figure 5-10: The 'Only identification window'.

Fill in the new name and make sure it ends with the proper extension (most likely .jpg) and press **Ok** next. Both image and fingerprint file will be renamed.



6 Some final thoughts on I³S

6.1 Recognition performance on ragged tooth sharks and whale sharks

Using the evaluation tool described in §4.1.6, I³S has been evaluated on a large newt database. The database consisted of 2627 images of 1074 individuals, and 2 reference images were used. The output of the test was:

```
Elaborate evaluation results
1000 repetitions, 2 reference images. #refs: 1666 #test: 961
#individuals: 1074 #images: 2627

Top #1: 874408 (90,99%)
Top #2: 901807 (93,84%)
Top #3: 911038 (94,80%)
Top #5: 920428 (95,78%)
Top #10: 931545 (96,93%)
Top #20: 938027 (97,61%)
```

Thus, when offering a photo of an individual with two photos of the same individual in the database, in 90,99% of the cases a proper match is shown as the first candidate, while in 96,93% of the cases one or more matches are shown in the top 10. All photos were taken under controlled circumstances. Results are likely to be less accurate when photos are taken under uncontrolled circumstances.

6.2 Speed of I³S

I³S can make use of the multiple cores available in all modern computer CPUs. If making full use of multi-threading, I³S is about 2.4 times faster compared to only a single thread (on the computer used for development, 2 cores). The options menu allows to set the maximum number of separate threads for recognition (see §4.1.5). Experiments indicate that it is not useful to have more threads than twice the number of processor cores/threads available to Java. By using all threads the computer may become unresponsive to other applications.

On the development hardware (Intel Core i5 3320M @ 2.60GHz from 2013, DDR3 RAM @ 800 MHz), with almost 26 spots on average per individual, comparison time between two photos with various numbers of threads is shown in the table below.

# threads	Time per comparison	Speed-up vs. 1 thread
1	9.27 msec	1,0
2	5.51 msec	1,7
4	4.16 msec	2,2
6	3.98 msec	2,3
8	3.94 msec	2,4



6.3 Limitations of I³S

Although the family of I³S tools has been shown to work on a large number of species, there are some limitations you should consider. Below we will discuss the two most important issues.

1. **2D vs. 3D.** The main limitation is that a 2D model is used for a 3D animal. Especially with increasing observation angles the limitations of the 2D approach become apparent. Experiments on I³S Spot showed that accuracy deteriorates considerably with angles larger than 40 degrees. For the moment we therefore advise to use photos taken from a viewing angle smaller than 30 degrees whenever possible. This is particularly important for the photos (to be) included in the identification database.
2. **Linearity.** We assume linearity of the animals. In plain English: we assume that the animals are rigid and their body parts are always in the same position with respect to each other, which is an optimal situation for comparison. Unfortunately, this is often not the case, especially if (e.g. with small animals) the entire body is used for identification. Using the head of animals has the advantage that you can safely assume linearity. The body is usually more susceptible to deformations, and the tail part even more.

6.4 Data capture

We have the following suggestions when collecting photo or video data:

1. If you capture your subject, i.e. you take it out of its habitat to be photographed, please make sure that:
 - There are no reflections from sunlight. These reflections will cause local high lights making features much harder to annotate. Try to shield your subject from direct exposure.
 - Take photos from the same angle, perpendicular to the identification area with all reference points visible.
 - If the entire body or a non-rigid area is used for identification, try to put your subject in a construction or rig where the identification area is always in the same position.
2. Do not use direct flash as this will cause local over exposure in your image. If flash is necessary, use indirect flash instead.
3. Do not reduce the resolution of the image. However, it is usually a good idea to crop the image showing only the relevant part. For example, Figure 6-1 shows the original photo at the left and a cropped version with only the relevant part at the right. Annotation and comparing images will be much easier with the right photo, while no information is lost provided you only crop and do not reduce resolution.
4. Try to get the viewing angle as close to perpendicular as possible. Analysis shows that most mismatches are caused by deviations from the ideal viewing angle.
5. Consider using HD video instead of photography. The advantage of videography is that it is possible to select the perfect frame.



Figure 6-1: Original photo (left) and cropped photo in the same resolution showing only the relevant part (right). (Image source: aquarium.co.za)

6.5 Is I³S right for your species?

The only way to find out is to set-up an experiment. Ideally, you have at least thirty individuals and for each individual three or more photos of the same area of interest (e.g. right side of the head is another area than the left side of the head of the same individual). If you have left and right side photos of the same individual, make sure to put them in another directory, e.g. Raggie73_Left and Raggie73_Right. Otherwise, the evaluation tool will count mismatches between right side photos and left side photos incorrectly as errors (the evaluation tool does not consider the metadata!). Annotate all usable photos, and evaluate the database using the evaluation tool (§4.1.6). If for example more than 95% of photos of the same individual turn up in the top 5, you have a good indication it might work for more data. Please do not hesitate to contact us at [i3s \[at\] reijns.com](mailto:i3s[at]reijns.com) to think along with you!

6.6 Under the hood of I³S

Finally, we will discuss some internal variables of I³S. You can find these variables in file `metadata.xml` (§3.3). The only way to change the values is by editing the file manually. Changing these variables may have a large (negative) impact on the recognition performance of I³S.

The relevant part of the metadata file is shown below:

```
<!-- Advanced settings: do not alter without instruction or
      really knowing what you are doing!!!! -->
<minNrElements> 12 </minNrElements>
<maxNrElements> 30 </maxNrElements>
<maxAllowedDistance> 0.01 </maxAllowedDistance>
<minRelativeDistance> 1.5 </minRelativeDistance>
<minRatioArea> 0.5 </minRatioArea>
<maxAllowedAngle> 40.0 </maxAllowedAngle>
<minRatioRatio> 0.66 </minRatioRatio>
```

Below we will discuss the variables. Four different variables are defined:

1. `MinNrElements/MaxNrElements`, these variables define the minimum and maximum number of spots to be annotated. The default numbers (12 resp. 30) are optimized for ragged tooth sharks. Keep in mind: too few spots is not distinctive enough. Too many may result in a



computationally expensive comparison, while increasing the possibility of a false positive match between two fingerprints.

2. `maxAllowedDistance`, a floating point variable which defines the maximum SQUARED distance between two matching spots relative to the maximum distance between any two reference points. In this case, 0.01 (10% squared) means 10% of this distance! This variable is used to prevent matches between spots which are too far apart.
3. `minRelativeDistance`, a floating point variable defining the minimum relative SQUARED distance between the best and second best matching spot. When comparing two fingerprints, i.e. two collections of spots, a spot from the first fingerprint might match with more than one spot from the second fingerprint. Usually, this happens more often in areas crowded with spots and this might result in a messy recognition. By demanding that the second best match is at a minimum distance of the best match, these messy recognitions are prevented improving the overall performance.

For example: the value is set to 1.5. Spot 1a (first fingerprint) matches with spot 2a and 2b (second fingerprint). The distance in recognition space between 1a and 2a is 9.5, and between 1a and 2b it is 8.1. The best match is therefore (1a, 2b). However, the relative distance between the two pairs is $9.5 / 8.1 = 1.173$. Squared this distance is 1.376, which is less than 1.5. Therefore the match between 1a and 2b is discarded.

4. `minRatioArea`, a floating point variable defining the minimum relative difference in size of two matching key points. Each key point is a circle with a size. In recognition space, the two fingerprints are corrected for scale variations. Nevertheless, it is not likely that two key points are exactly equal in size. Far from that, the automatic key point extraction is often quite accurate in the location, but circle sizes have a significant variation. This variable sets a limit to the difference in circle size which is allowed.

For example: the value is set to 0.5. Key point 1 has a radius of 5, key point 2 has a radius of 4. The area of a circle = $\pi * \text{radius} * \text{radius}$, consequently the areas for key point 1 and 2 are 78.5 and 50.3 respectively. The relative difference in size is therefore $50.3 / 78.5 = 0.64$. Because $0.64 > 0.5$ the size difference is acceptable.

5. `maxAllowedAngle`, Each ellipse (except a circle) has an angle which is defined as the angle between the long axis and the x-axis. The difference between the angles of two ellipses is also a useful measure of similarity. This difference has a value from 0 degrees (perfect) to 90 degrees (perpendicular, worst case). This variable sets a limit to the maximally allowed difference in this angle for two spots to match.

When two ellipses are almost a circle, the calculation of the angle is prone to be inaccurate. To prevent that matching of two very similar spots, which are almost circular is rejected due to these inaccuracies, I³S only calculates an angle for sufficiently elongated ellipses. If the ratio between the short and long axis is more than 2/3, the angle is not calculated and not part of the matching process. A spot with an angle and a spot without an angle can match provided their size is sufficiently similar.

6. `minRatioRatio`, The shape of each ellipse is defined by its eccentricity or ratio between the short and the long axis. A ratio of 1 (axes are equal) means a circle, while a ratio of 0.01 will yield an extremely elongated ellipse. For two ellipses to match, their ratios should be similar. This variable sets a limit to difference in ratios, i.e. a ratio of ratios.



For example: let's assume the limit is set to 0.75. Spot 1 has a long axis of length 12 and a short axis of 7, resulting in a ratio of $7/12 = 0.58$. Spot 2 has a long axis of 8 and a short axis of 6.5, resulting in a ratio of $6.5/8 = 0.81$. The ratio of ratios is now $0.58 / 0.81 = 0.72$ which is less than 0.75. As a consequence, the potential match between these spots is rejected.