**Tutor notes for Trade-Off Workshop**

**Preliminary.**

First, read the paper by Vincent (2017) from the collection of papers provided. This will explain the basic idea behind using trade-offs in biomimetics, an approach that can be developed into a system for transferring the classification and solution of problems between a range of disciplines.

The slide show introduces the concept of trade-offs and their utility and how they pull the ideas and concepts of this Workshop into relation with each other. I strongly hope that if you run this workshop you will take notes on the strengths and weaknesses that you find and let me know on j.vincent@hw.ac.uk. That way together we can refine and improve both the workshop and the underlying concepts.

**Trade-offs and their resolutions**

These notes are taken from studies using the categories listed in the Excel sheets of the Trade-Off Parameters (TOPs, the factors that define the trade-off) and the Inventive Principles ((IPs, the resolutions of the trade-offs). Some of the supplied papers have highlighting which identifies these.

The organisation of the Excel sheets is based on a TRIZ model of the so-called “Contradiction Matrix”. There is plenty of information about this on the internet. The way I have used it is different, though, and I am not supplying a copy of the Matrix because (a) it is not based on biology, and (b) you don’t need it. Reading across the columns, the Excel sheets show an index number (relating to the original TRIZ lists). They are not really needed here but I have included them so that you can find your way around the lists more easily. The two sets of docx sheets that have the TOPs and IPs illustrated to show the tree structure of the terms are organised in a similar fashion. The next column is my name for the TOP or IP and relates fairly closely to the original TRIZ names. The following columns, reading left to right, go into further detail, less and less reliant on the TRIZ versions. In the TOPs (which describe a biological system) they tend to be more biological. In the IPs list they are more neutral or technical, since these are the recommendations for a biomimetic equivalent. This is discussed in greater detail in Vincent (2017). You should examine the hierarchy of suggestions within each IP since this can give ideas for better transfer of the biological concepts. In TRIZ, which is solely concerned with engineering, there are up to 150 different effects for the delivery of each IP. These lists are freely available on the internet.

**NOTE: In the following, the Trade-Off Parameter is read from the TOP list and the resolution is read from the IP list**

In each case the TOP or IP is taken from anywhere on the list, according to what is appropriate. It can help in understanding to work through their tree structure and see how a particular TOP can be resolved by a common basic principle but that different way of achieving that basic principle is used by different organisms and examples of the trade-off, depending on the detail of definition of the trade-off and the constraints on the resolution. This is illustrated in the Vincent (2017) paper with the speed-accuracy trade-off.

**Adaptive shape changing (1)**

Green

Trade-off: 12 - shape change / 13 - internal stability

Resolution: 14 - convert flat surface to undulating / 17 - develop sculptured surface / 1 - generate a pattern / 29 - use a closed-ended hydrostat / 30 - use a shell that can buckle elastically

Longo

Trade-off: 13 - Internal stability / 35 - adaptiveness

Resolution: 5 - bind selectively / 15 - deploy a structure / 4 - use asymmetry of behaviour / 3 - local properties

Reid

Trade-off: 10 – force affecting object / 23 - loss of material

Resolution: 34 – dynamic instability / 15 – make parts independently responsive / 23 – mechanical feedback / 1 – use modularisation

Weihs

Trade-off: 13 – internal stability / 35 – ability to change direction

Resolution: 22 – destabilise the system / 15 – ensure structure is flexible / 15 – make parts independently responsive / 29 – use a flapping foil / 4 – use asymmetry of shape

**Adaptive shape changing (2)**

Carruthers

Trade-off: 12 – shape / 37 – complexity of system

Resolution: 25 – develop and automatic response / 3 – devise a system in which each part fulfils a different function / 1 – methods for subdivision of a surface / 15 – progress to optimal operating conditions

Combes:

Trade-off: 12 – Shape change / 14 – resistance to external forces

Resolution: 25 – develop autonomous repair mechanism / 15 – make parts independently movable / 30 – use a dynamic membrane / 3 – use a locally flexible system

Marsh

Trade-off: 9 – change of speed / 13 – internal stability

Resolution: 22 – add a secondary harmful effect that neutralises the primary effect / 19 – change periodicity of action / 15 - make parts independently moveable / 4 - make parts independently moveable

Gosavi

Trade-off: 12 – geometrical parameter / 27 - predictable output

Resolution: 10 - adapt morphology / 6 - develop universal function / 1 - divide the object into two or more units / 15 - make parts independently responsive / 2 – separation in s[ace

**Deployable Structures**

Ferguson

Trade-off: 18 – light direction / 25 – speed of reflex reaction

Resolution: 15 - deploy a structure / 1 - methods for subdivision of a surface / 24 - use a sensor to monitor mediation / 23 - use gravity feedback / 1 - use modularisation

Haas

Trade-off: 5 - area of body surface / 30 - exposure to harmful loads

Resolution: 1 – develop subunits / 15 – deploy a structure / 12 – use an elastic energy store

Longo

Trade-off: 13 - Internal stability / 35 - adaptiveness

Resolution: 5 - bind selectively / 15 - deploy a structure / 4 - use asymmetry of behaviour / 3 - local properties

Glaser

Trade-off: 6 - surface area / 20 - energy needed for physical processes

Resolution: 15 - deploy a deformation along a structure / 35 - remove plasticiser / 29 - use hydraulically driven expansion / 3 - use local properties

Eylers

Trade-off: 11 - tensile stress / 14 - resistance to internal forces

Resolution: 15 - deploy a structure / 1 - divide the object into two or more units / 5 - group similar objects together

**Eat or be eaten**

Johnsson

Trade-off: 19 – food / 30 - exposure to high intensity light

Resolution: 24 - dissolve boundaries / 32 - generate countershading / 24 - reflect radiation intensity / 21 - use speed if the process is harmful to self

Dammhahn

Trade-off: 19 – food / 30 – exposure to predation

Resolution: 10 - acquire resource / 16 – be bold / 15 - means to increase adaptiveness

Abrams

Trade-off: 19 – food / 30 – exposure to predation

Resolution: 15 - means to increase adaptiveness / 9 - prepare a behavioural defence / 35 – scaling effects / 23 - use behavioural feedback

Bennet

Trade-off: 19 – food / 30 – exposure to predation

Resolution: 10 - adapt morphology / 15 - change phenotype / 35 – expansion / 23 - use behavioural feedback

Langerhans

Trade-off: 19 – net energy available to moving object / 30 – exposure to predation

Resolution: 10 - adapt morphology / 35 – change dimensions / 13 - change from predictable to chaotic / 21 - make a sudden movement

Thaler

Trade-off: 19 – food / 30 – exposure to predation

Resolution: 15 - change developmental process / 9 - let a population migrate / 20 - work at full capacity

**Better data capture**

Göpfert

Trade-off: 35 – sound intensity / 18 - adaptiveness

Resolution: 14 - convert from translation to rotation / 23 - set sensitivity inverse to input signal / 18 - use a resonating system / 4 – use asymmetry of shape

Sandeman

Trade-off: 18 - vibration of substrate / 24 - ineffective transmission of data

Resolution: 31 – make a plane with multiple holes / 18 - use a structure that can vibrate in-plane / 18 - use a vibrating surface with no edge constraint / 18 - vibrate at a range of frequencies

Ala-Laurila

Trade-off: 24 - bad signal-to-noise ratio / 27 - sensory discrimination

Resolution: 15 - change response threshold / 1 - divide the object into two or more units / 3 - localise processing / 5 - make operations parallel / 15 - make parts independently responsive

Latash

Trade-off: 9 – rate of process / 24 - ineffective transmission of data

Resolution: 6 – develop universal functionality of components / 5 - generate a network / 6 - trim the number of components

Chou

Trade-off: 24 - bad signal-to-noise ratio / 28 – control of error

Resolution: 35 - change amplitude / 2 - filter noisy signal / 7 – use interlocked inner and outer process loops / 23 - use positive feedback

**Friendly fire**

Johnsen

Trade-off: 19 – food / 30 - exposure to high intensity light

Resolution: 24 - dissolve boundaries / 32 - generate countershading / 24 - reflect radiation intensity / 21 - use speed if the process is harmful to self

Merilaita

Trade-off: 30 – disruptive camouflage / 37 - cost of measurement

Resolution: 24 - dissolve boundaries /1 – methods of subdivision of surface / 32 - dissolve boundaries /

Parker

Trade-off: 27 - ability to communicate /30 - exposure to predation

Resolution: 28 - change from sound to light / 32 - change iridescence /40 - generate a layered composite /24 - modify radiation conditions /26 - reflection or optical copy

Garcia

Trade-off: 24 - bad signal-to-noise ratio /30 - exposure to predation

Resolution: 32 - generate countershading /26 - replace a visible copy with UV or IR reflecting copy / 32 - use disruptive colouration /3 - use local properties

**Quickly or accurately**

Lambert

Trade-off: 9 – speed of execution / 28 - prediction of dimension

Resolution: 15 – make parts independently movable /23 - use position feedback /

Ings

Trade-off: 25 - shorter duration of an activity /28 – control of error

Resolution: 12 – spread risk evenly / 9 – take avoiding action / 23 - learn

Goldfarb

Trade-off: 9 - speed of reaction or response /29 – product as specified

Resolution: 5 – use an integrated accumulator / 15 -- prepare for action / 10 -- develop ability to predict / 23 -- use error correction

Heitz

Trade-off: 9 - speed of reaction or response / 28 – control of error

Resolution: 15 – change response threshold / 5 - use an integrated accumulator / - use an intermediary

Malcom

Trade-off: 9 – speed of process / 29 – product as specified

Resolution: 15 -- adaptive control / 5 -- generate a network / 16 -- perform a partial or excessive reaction / 35 -- scaling effects

Marshall

Trade-off: 9 - speed of reaction or response / 28 – control of error

Resolution: 5 -- accumulate information / 2 -- filter noisy signal / 23 -- use error correction

**Stable or maneuverable**

Bartol

Trade-off: 27 -- predictable output / 30 -- exposure to fluid turbulence

Resolution: 14 -- generate vorticity / 23-- initiate stability control / 3 -- localise processing / 8 -- use a leading edge vortex / 4 -- use asymmetry of force / 25 – develop an autonomous response

Weihs

Trade-off: 13 -- internal stability / 35 -- ability to change direction

Resolution:22 – convert harm to benefit / 15 -- ensure structure is flexible / 15 -- make parts independently responsive / 4 -- use asymmetry of shape

Studer

Trade-off: 13 -- internal stability / 35 -- responsive to internal change

Resolution: 22 -- destabilise the system / 15 -- make parts independently responsive / 3 – use local properties

**Life or death**

Brierley

Trade-off: 19 -- driver of oxidation / 30 -- exposure to predation

Resolution: 13 -- change from predictable to chaotic / 1 -- methods for subdivision of a surface

Morgan

Trade-off: 27 -- reliable outcome / 30 -- exposure to predation

Resolution: 19 – change periodicity of action / 15 – change phenotype / 10 – diurnal activity / 3 -- introduce patchiness

Abrams

Trade-off: 29 – food / 30 -- exposure to predation

Resolution: 15 -- means to increase adaptiveness / 9 -- prepare a behavioural defence / 35 – change a parameter / 23 -- use behavioural feedback

Bennett

Trade-off: 29 – food / 30 -- exposure to predation

Resolution: 10 -- adapt morphology / 15 – change phenotype / 23 -- use behavioural feedback / 35 -- expansion

**Tough materials**

De Blasio

Trade-off: 7 – volume of animal / 14 -- resistance to external forces

Resolution: 14 -- convert to fractal curves / 5 – segment before merging

Currey

Trade-off: 10 -- internal force generated / 14 -- resistance to fracture

Resolution: 17 -- change orientation / 40 -- control fibre angle / 34 – discard and recover / 40 -- generate a layered composite

Koh

Trade-off: 14 -- resistance to fracture / 31 -- inadequate strength

Resolution: 5 -- generate a network / 40 -- reinforce with high stiffness fibre / 1 – use branching / 3 – use local properties

Chiang

Trade-off: 14 -- adhesive strength / 30 -- exposure to high level of elastic energy

Resolution: 5 -- bind selectively / 12 -- minimise free energy / 10 -- store elastic energy /

30 -- use a tensile membrane / 24 -- use an adhesive