What is Affective Computing?

Dr. Rosalind Picard of MIT Media Laboratory coined the term *Affective Computing* in 1994 and published the first book on Affective Computing in 1997.

According to Picard -

"…computing that relates to, arises from, or deliberately influences emotions"

Picard, R. 1995. *Affective Computing*. M.I.T Media Laboratory Perceptual Computing Section Technical Report
Picard, R. 1995. *Affective Computing*. The MIT Press

- **A community of practice:** HUMAINE Association, 2007

  Represented by a professional society

  Now, Association for the Advancement of Affective Computing

aaac
emotion-research.net

❖ a professional, world-wide association for researchers in Affective Computing, Emotions and Human-Machine Interaction

- International Conference ACII (bi-annual International Conference, started in 2005)

- International Journal (started in 2010)

Affective Computing

Motivations and Goals

- ☐ Research shows that human intelligence is not independent of emotion. Emotion and cognitive functions are inextricably integrated into the human brain.

- ☐ Automatic assessment of human emotional/affective state.

- ☐ Creating a bridge between highly emotional human and emotionally challenged computer systems/electronic devices - Systems capable of responding emotionally.

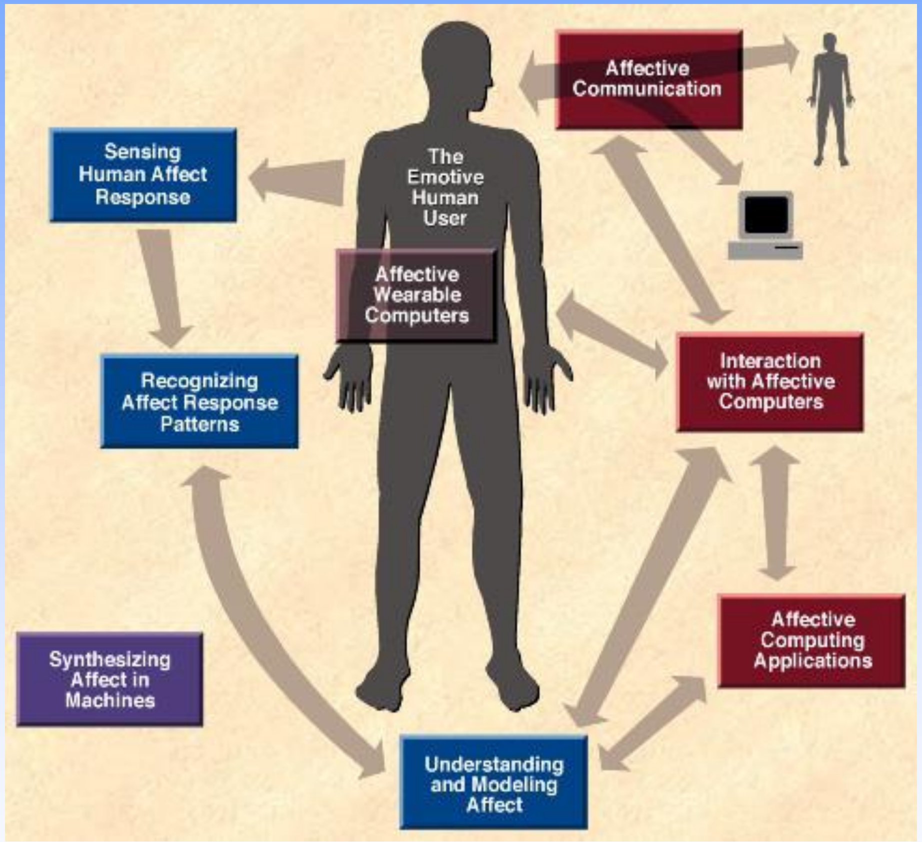
- ☐ The central issues in affective computing are representation, detection, and classification of users emotions.

Norman, D.A. (1981). 'Twelve issues for cognitive science'
Picard, R., & Klein, J. (2002). Computers that recognize and respond to user emotion: Theoretical and practical implications.
Taleb, T.; Bottazzi, D.; Nasser, N.; , "A Novel Middleware Solution to Improve Ubiquitous Healthcare Systems Aided by Affective Information,"

Affective Computing Research

Affective computing can be related to other computing disciplines such as

- Artificial Intelligence (AI),
- Virtual Reality (VR) and
- Human Computer interaction (HCI).



The research areas of affective computing visualized by MIT (2001)

Questions need to be Answered?

- What is an affective state (typically feelings, moods, sentiments etc.)?
- Which human communicative signals convey information about affective state?
- How are various kinds of affective information can be combined to optimize inferences about affective states?
- How to apply affective information to designing systems?

M. Pantic, N. Sebe, J. F. Cohn, and T. Huang, 2005. Affective multimodal human-computer interaction. In *ACM International Conference on Multimedia (MM)*.

Affective Computing Research

Steps towards affective computing research

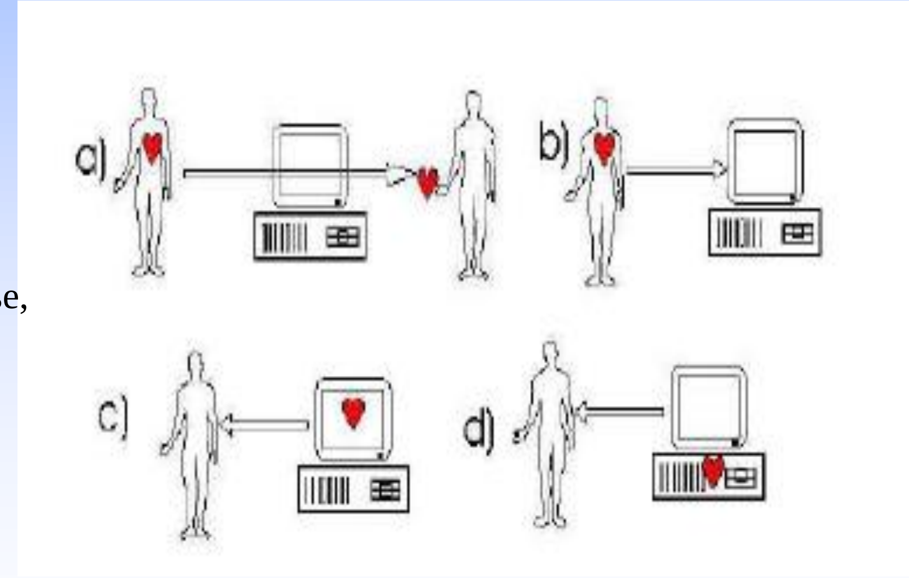
- ☐ We first need to define what we mean when we use the word emotion.
- ☐ Second, we need an *emotion model* that gives us the possibility to differentiate between emotional states.
- ☐ In addition, we need a *classification scheme* that uses specific features from an underlying (input) signal to recognize the user's emotions .
- ☐ The emotion model has to fit together with the classification scheme used by the emotion recognizer.

R. Sharma, V. Pavlovic, and T. Huang. Toward multimodal human-computer interface. In *Proceedings of the IEEE*, 1998.

How Emotion/Affection is Modeled?

According to *Boehner et al.* -

In affective computing, affect is often seen as another kind of information – discrete units or states internal to an individual that can be transmitted in a loss-free manner from people to computational systems and back.



Affection description perspectives –

- Discrete Emotion Description
  - Happiness, fear, sadness, hostility, guilt, surprise, interest
- Dimensional Description
  - Pleasure, arousal, dominance

Boehner, K., DePaula, R., Dourish, P. & Sengers, P. 2005. Affect: From Information to Interaction
Taleb, T.; Bottazzi, D.; Nasser, N.; , "A Novel Middleware Solution to Improve Ubiquitous Healthcare Systems Aided by Affective Information,"
Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications,"
Burkhardt, F.; van Ballegooy, M.; Engelbrecht, K.-P.; Polzehl, T.; Stegmann, J.; , "Emotion detection in dialog systems: Applications, strategies and challenges,"

Skills of Emotional Intelligence:

- Recognizing emotions
- Having emotions
- Expressing emotions
- Regulating emotions
- Utilizing emotions

if "have emotion"

Affection Detection and Recognition

Techniques and Methodologies

Affection detection sources:

- Bio-signals (Psychological sensors, Wearable sensors)
  - Brain Signal, skin temperature, blood pressure, heart rate, respiration rate
- Facial Expression
- Speech/Vocal expression
- Gesture
  - Limbic movements
- Text

Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications,“
Leon, E.; Clarke, G.; Sepulveda, F.; Callaghan, V., "Optimised attribute selection for emotion classification using physiological signals”

Affection Detection and Recognition

Techniques and Methodologies

Affection recognition modalities

- Unimodal
  - primitive technique
- Multimodal
  - provide a more natural style for communication

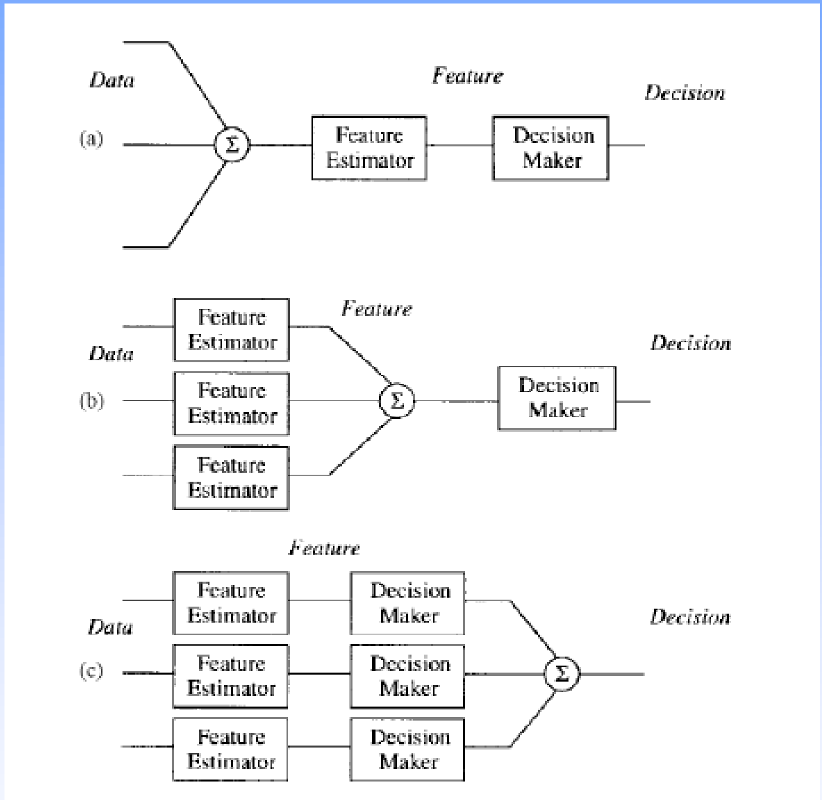


Figure 1: Three levels for multimodal fusion (from Sharma et al. 1998): a) data or signal fusion; b) feature fusion; c) decision fusion

Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications
Zhihong Zeng; Pantic, M.; Roisman, G.I.; Huang, T.S.; , "A Survey of Affect Recognition Methods: Audio, Visual, and Spontaneous Expressions,"

Affection Recognition Method

Voice / Speech

- Paralinguistic Features of Speech – *how is it said?*
- Prosodic features (e.g., pitch-related feature, energy-related features, and speech rate)
- Spectral features (e.g., MFCC - Mel-frequency cepstral coefficient and cepstral features)
- Spectral tilt, LFPC (Log Frequency Power Coefficients)
- F0 (fundamental frequency of speech), Long-term spectrum
- Studies show that *pitch* and *energy* contribute the most to affect recognition
- Speech disfluencies (e.g., filler and silence pauses)
- Context information (e.g., subject, gender, and turn-level features representing local and global aspects of the dialogue)
- Nonlinguistic vocalizations (e.g., laughs and cries, decode other affective signals such as stress, depression, boredom, and excitement)

Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications

Affection Recognition Method

Speech Recognition Architecture

Speech Signal

- Accuracy rates from speech are somewhat lower (35%) than facial expressions for the basic emotions .

- *Sadness, anger,* and *fear* are the emotions that are best recognized through **voice**, while *disgust* is the worst.

Pre-processing → Feature Extraction → Classification

Classified Result

Audio recordings collected in call centers and, meetings, Wizard of Oz scenarios interviews and other dialogue systems

]M. Pantic, N. Sebe, J. F. Cohn, and T. Huang. Affective multimodal human-computer interaction. In *ACM International Conference on Multimedia (MM),* 2005.
Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications

Affection Recognition Method

Facial Expression

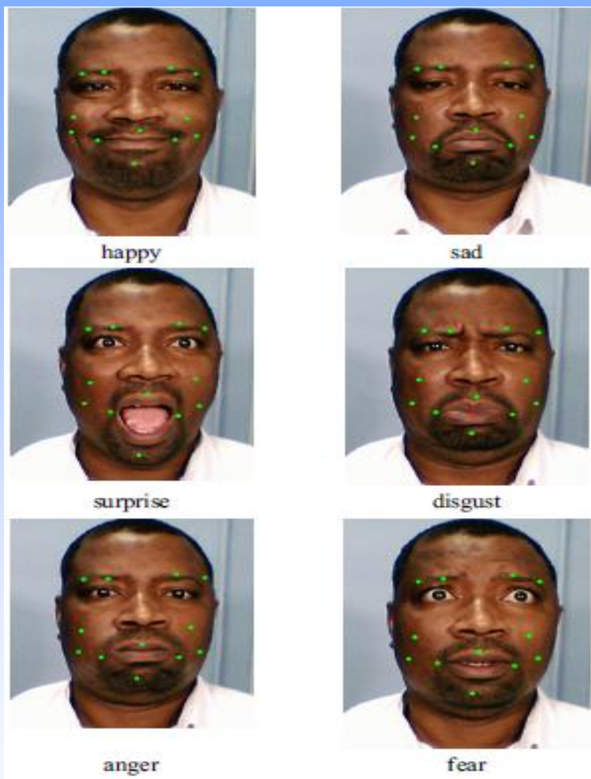
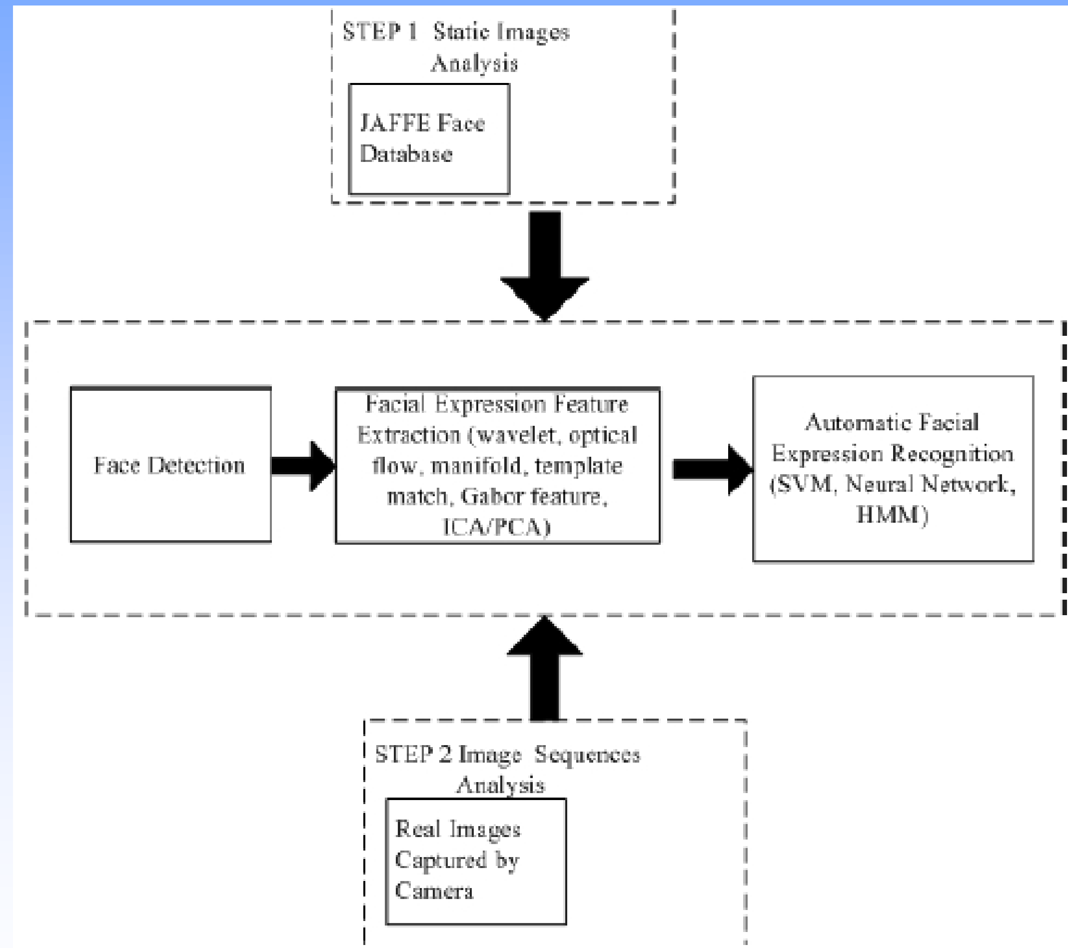


Fig. 1 Samples of the six basic universal emotions

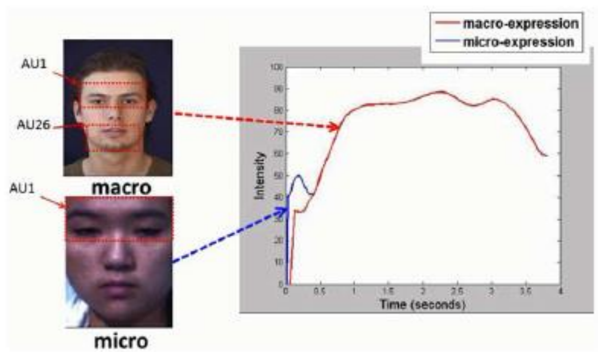
[25]



[27] Figure 1. Schematic of Facial Expression Recognition

Facial Expression Recognition

- Mug Shot
- Dynamic Information
  - Action Units
  - Prototypic Emotional Expressions



Psychological studies have suggested that the facial motion is fundamental to the recognition of facial expressions.

Emotion recognition from facial expressions

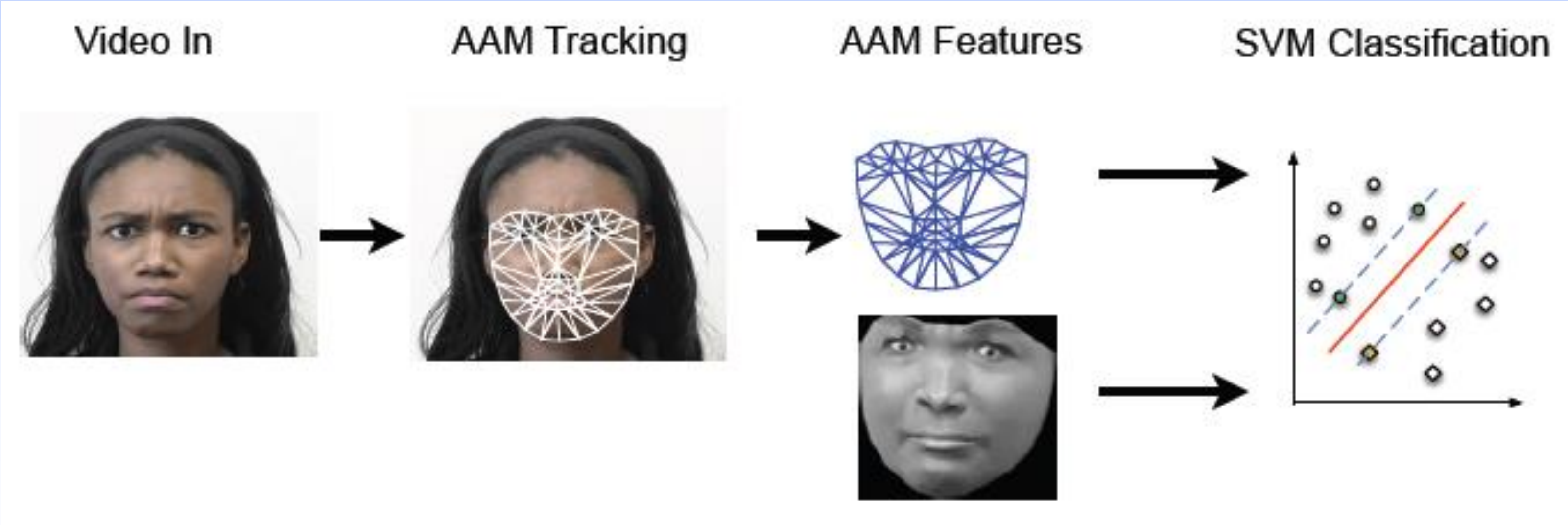
- Feature extraction
  - Appearance features
    - Local binary pattern
    - Local binary pattern from three orthogonal planes
    - Gabor, HOG, SIFT(*Scale-invariant feature transform*), etc.
  - Shape features
    - Distance between facial landmarks, angle, coordinates of facial landmarks, etc.
    - To locate facial landmarks using ASM, AAM, CLM, DRMF(Discriminative Response Map Fitting), etc.

Affection Recognition Method

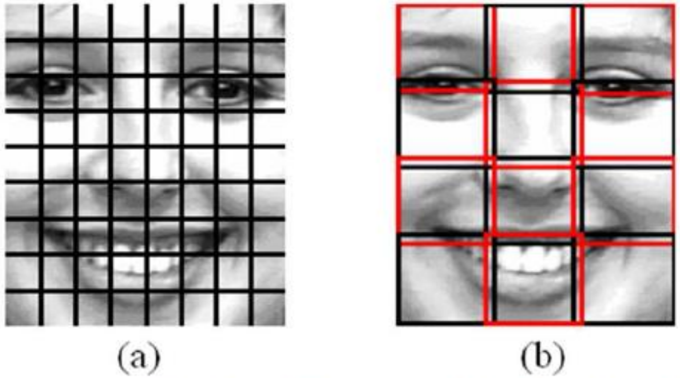
Facial Expression

Example: Active Appearance Model (AAM) [26]

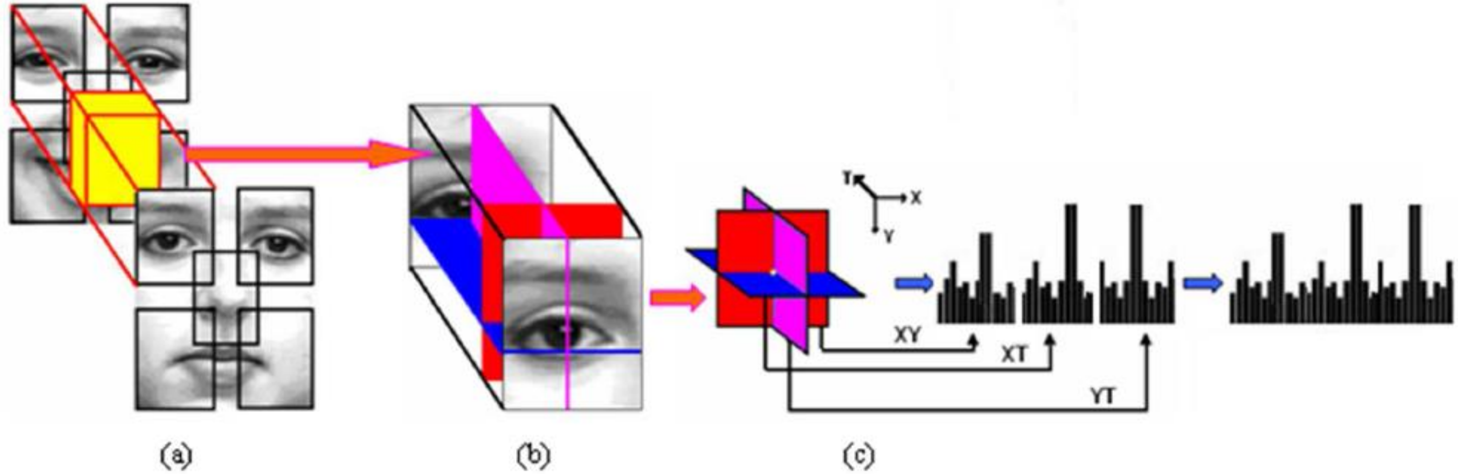
(AAM) based system which uses AAMs to track the face
and extract visual features. Support vector machines are used
(SVMs) to classify the facial expressions and emotions.



Example: LBP-TOP



(a) Non-overlapping blocks(9 x 8)   (b) Overlapping blocks (4 x 3, overlap size = 10)

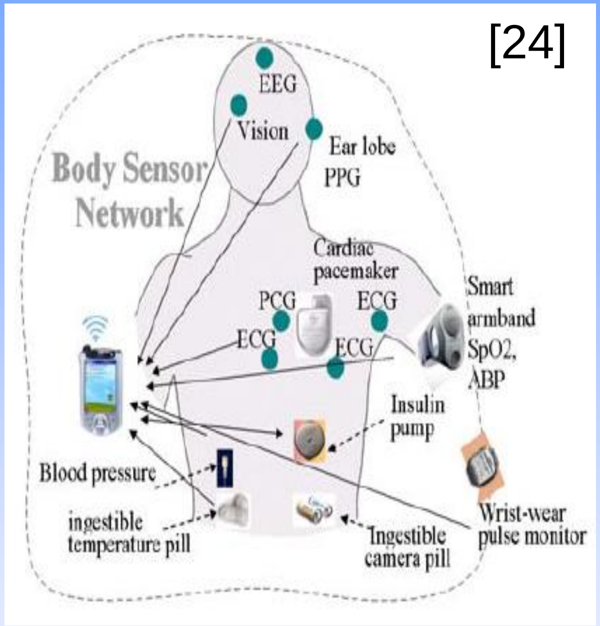


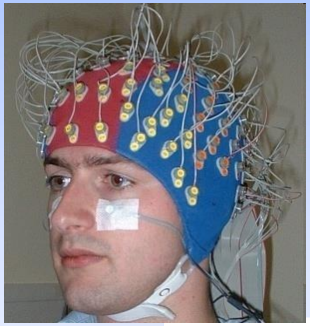
(a) Block volumes   (b) LBP features from three orthogonal planes   (c) Concatenated features for one block volume with the appearance and motion

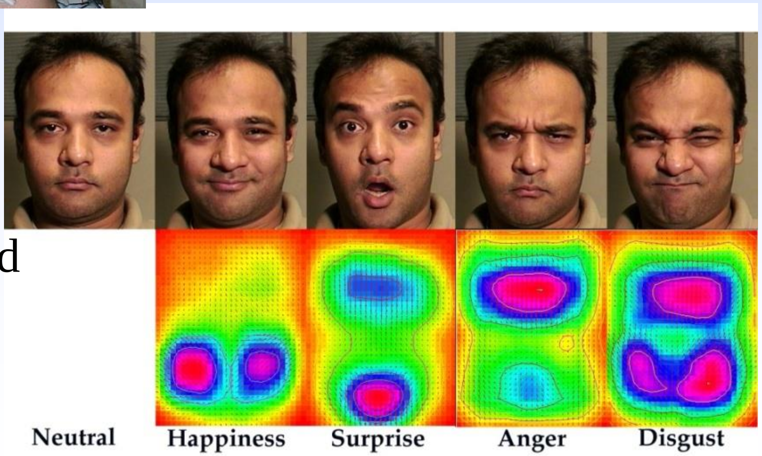
Affection Recognition Method

Psychological/Bio-Signals Signals

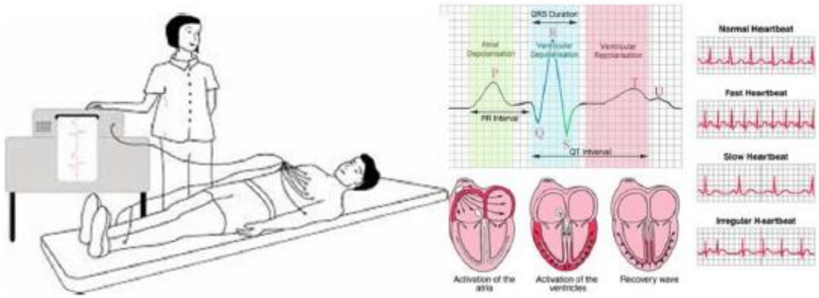
- Physiological signals derived from Autonomic Nervous System (ANS) of human body.
  - Fear for example increases heartbeat and respiration rates, causes palm sweating, etc. [8]
- Psychological Metrics used are [23]:
  - GSR - Galvanic Skin Resistance
  - RESSP - Respiration
  - BVP - Blood Pressure
  - Skin Temperature
- Electroencephalogram (EEG), Electrocardiography (ECG), Electrodermal activity (EDA)], Electromyogram (EMG) [8][9][23]
- Skin conductivity sensors, blood volume sensors, and respiration sensors may be integrated with shoes, earrings or watches, and T-shirts [8] [9]



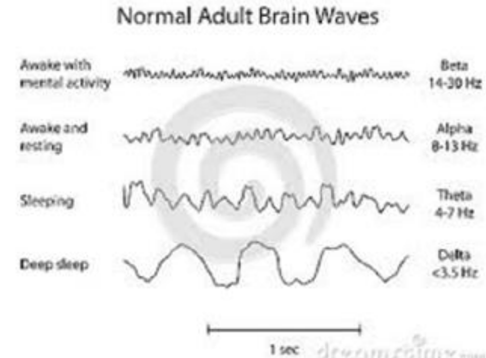




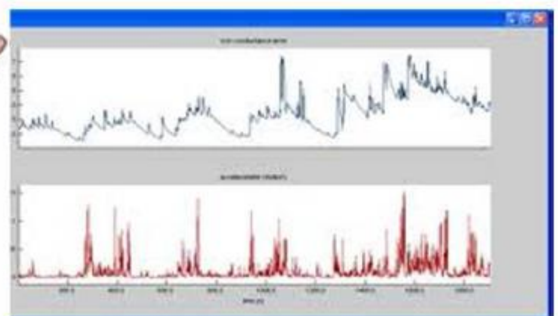
Electroencephalogram (EEG), Electrocardiography (ECG), Electrodermal activity (EDA), Electromyogram (EMG)



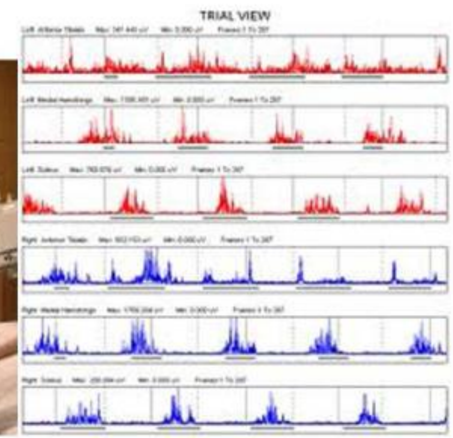
ECG: recording of the electrical activity of the heart



EEG: recording of electrical activity along the scalp



EDA: to measure the electrical conductance of skin, which varies depending on the amount of sweat-induced moisture on the skin.



EMG: for evaluating and recording the electrical activity produced by skeletal muscles.

Affection Recognition Method

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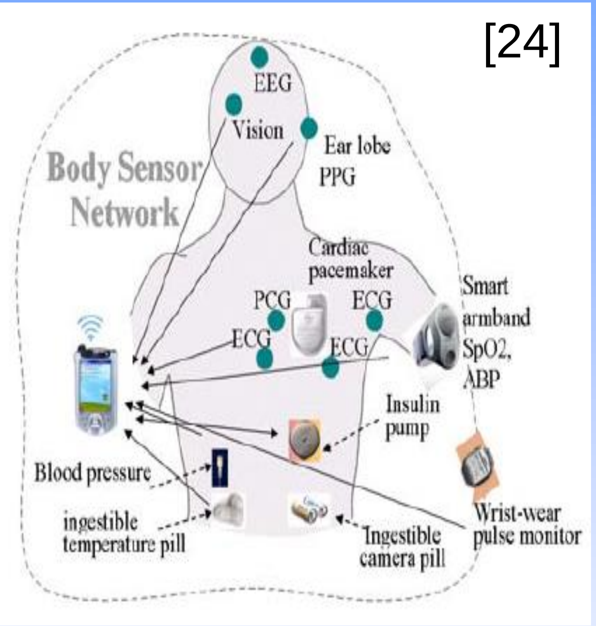

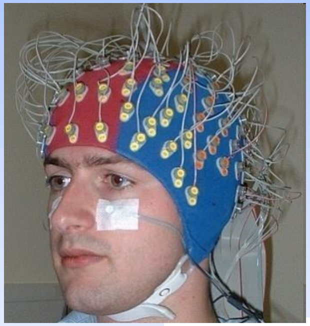

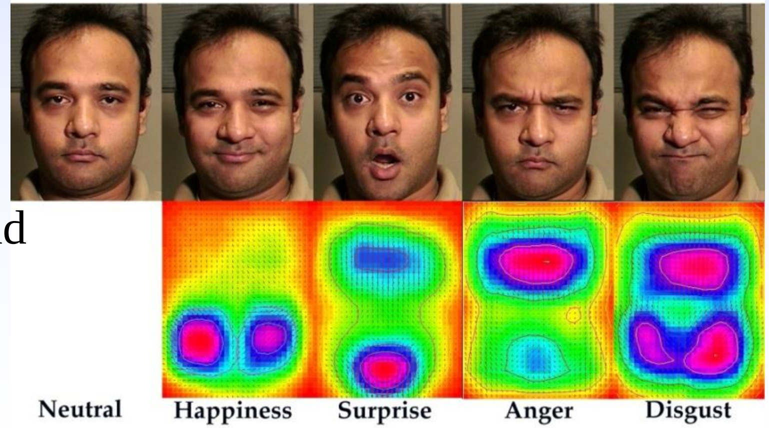

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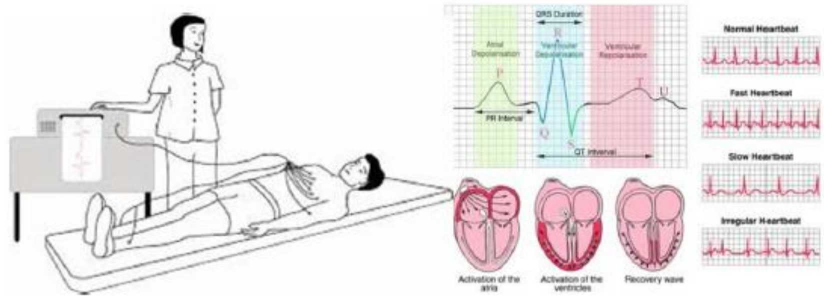

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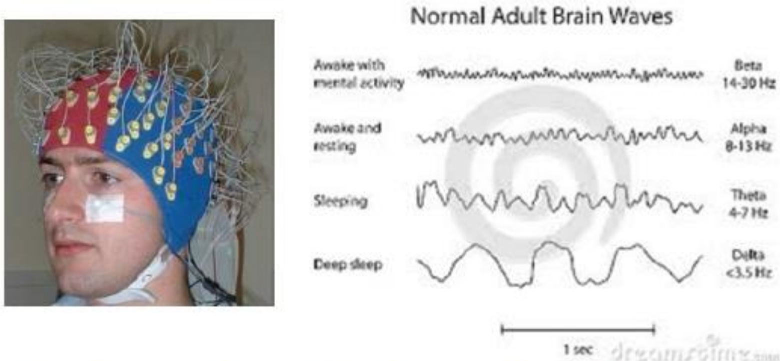

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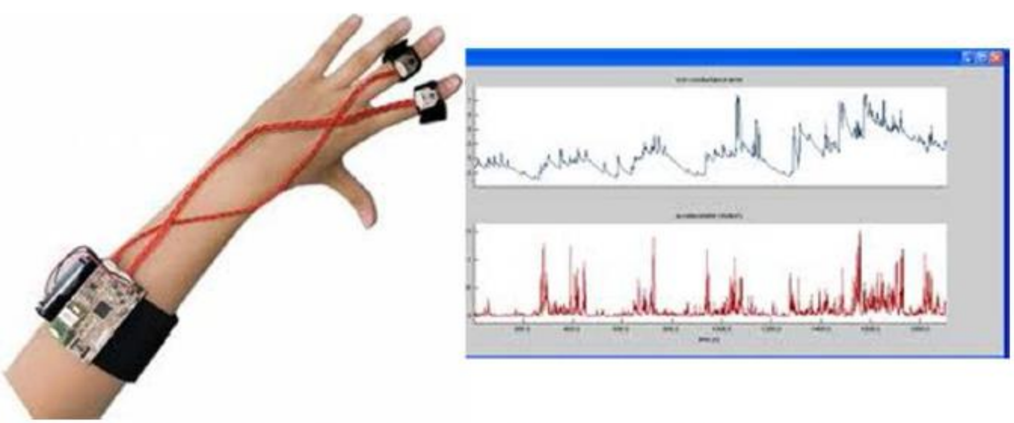
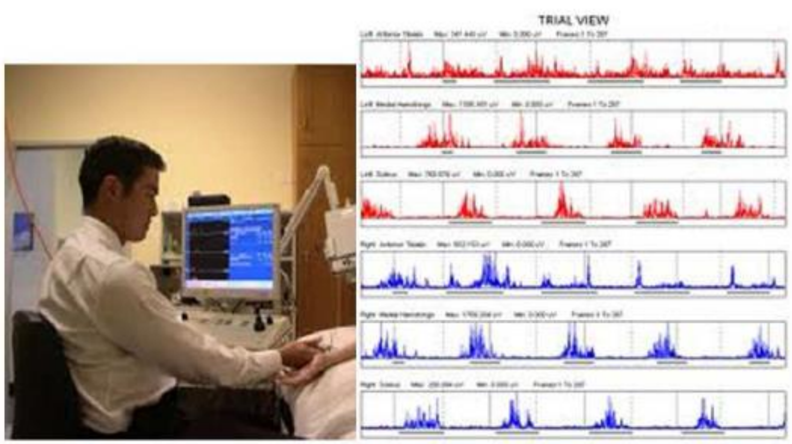


EDA: to measure the electrical conductance of skin, which varies depending on the amount of sweat-induced moisture on the skin.



EMG: for evaluating and recording the electrical activity produced by skeletal muscles.

Affection Recognition Method

Gesture / Body Motion

- Pantic et al.'s survey shows that gesture and body motion information is an important modality for human affect recognition. Combination of face and gesture is 35% more accurate than facial expression alone [21].
- Two categories of Body Motion based affect recognition [22]
  - Stylized
    - The entirety of the movement encodes a particular emotion.
  - Non-stylized
    - More natural - knocking door, lifting hand, walking etc.

Example: Applying SOSPDF (shape of signal probability density function) feature description framework in captured 3D human motion data [22]

Frequently used Modeling Techniques

- Fuzzy Logic
- Neural Networks (NN)
- Hybrid: Fuzzy + NN
- Tree augmented Naïve Bayes
- Hidden Markov Models (HMM)
- K-Nearest Neighbors (KNN)
- Linear Discriminant Analysis (LDA)
- Support Vector Machines (SVM)
- Gaussian Mixture Models (GMM)
- Discriminant Function Analysis (DFA)
- Sequential Forward Floating Search (SFFS)

Emotion Markup Language

- **Annotation of material involving emotionality**
- **Automatic recognition of emotions from sensors**
- **Generation of emotion-related system responses: speech, music, colors, gestures, synthetic faces**
- **Emotion vocabularies and representations:**

Term
anger
disgust
fear
happiness
sadness
surprise

<emotion category-set="http://www.w3.org/TR/emotion-voc/xml#big6"> <category name="surprise" confidence="0.9 </emotion>

Emotion Representation

Computing and Communication

```
<emotionml xmlns="http://www.w3.org/2009/10/emotionml">
    <metadata>
        <name>robbie the robot example</name>
    </metadata>

    <!-- Appraised value of incoming event -->
    <emotion>
        <modality mode="senses"/>
        <appraisals set="scherer_appraisals_checks">
            <novelty value="0.8" confidence="0.4"/>
            <intrinsic-pleasantness value="-0.5" confidence="0.8"/>
        </appraisals>
    </emotion>

    <!-- Robots current internal state configuration -->
    <emotion>
        <modality mode="internal"/>
        <dimensions set="arousal_valence_potency">
            <arousal value="0.3"/>
            <valence value="0.9"/>
            <potency value="0.8"/>
        </dimensions>
    </emotion>
```

W3C standard for emotion representation Emotion Markup Language (EmotionML) 1.0 [20]

Effects of mood on decision making

(Lerner & Keltner 2000, 2001, 2004)

A person's mood at the time of decision-making also influences issue interpretation and his or her choice under risk.

Happiness

Optimistic about judgments of future events

Anger

Optimistic judgments of future events,
Risk-Seeking choices

Pessimistic judgments of future events,
Risk-Aversive choices

Fear

Pessimistic about the present and make a choice to change the current sad state.
Reverse Endowment Effect

Sadness

Applications

- In the security sector affective behavioural cues play a crucial role in establishing or detracting from credibility
- In the medical sector, affective behavioural cues are a direct means to identify when specific mental processes are occurring
- Neurology (in studies on dependence between emotion dysfunction or impairment and brain lesions)
- Psychiatry (in studies on schizophrenia and mood disorders)
- Dialog/Automatic call center Environment – to reduce user/customer frustration
- Academic learning
- Human Computer Interaction (HCI)

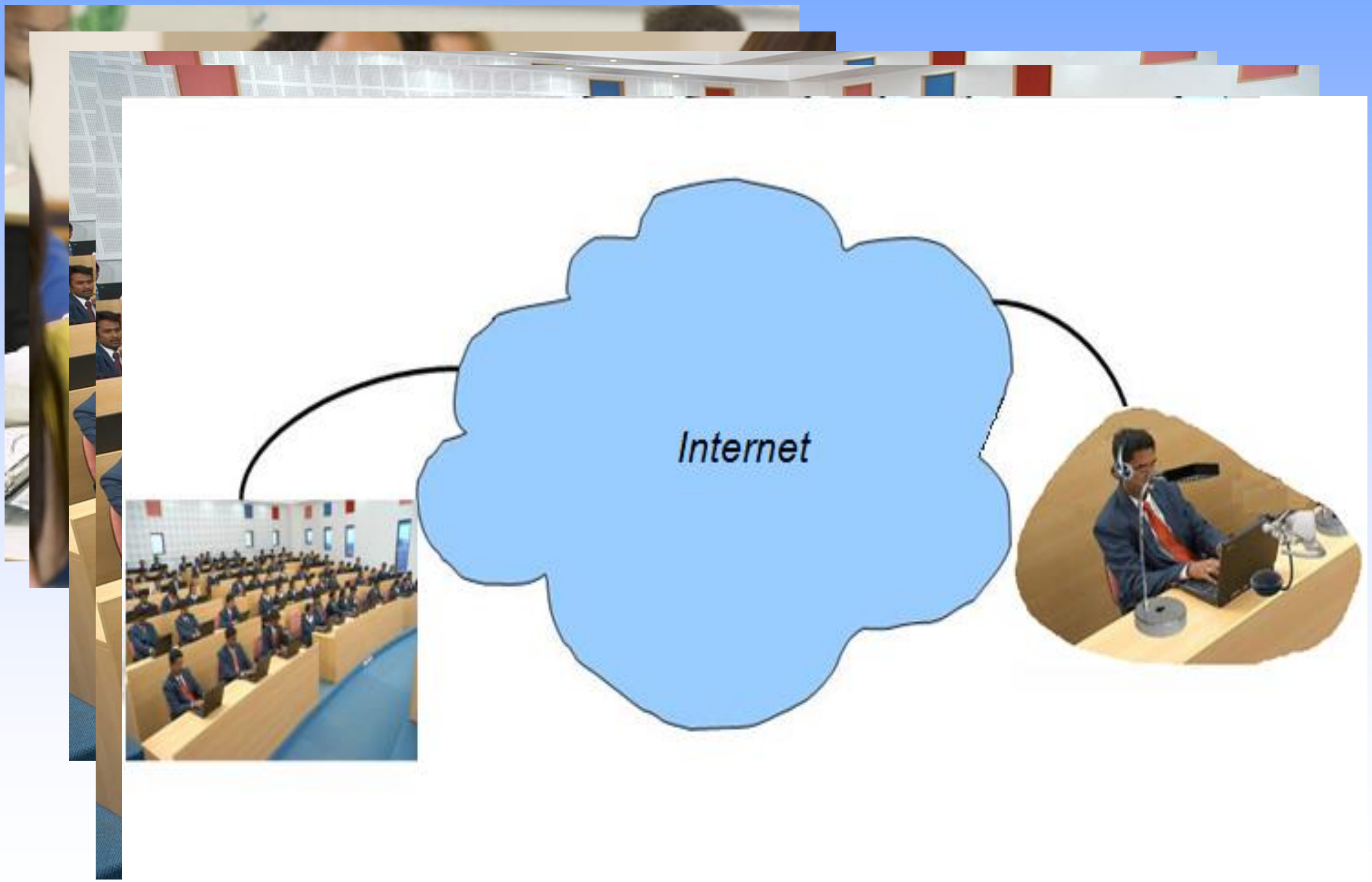
Zhihong Zeng; Pantic, M.; Roisman, G.I.; Huang, T.S.; , "A Survey of Affect Recognition Methods: Audio, Visual, and Spontaneous Expressions," *Pattern Analysis and Machine Intelligence*

Future Research Directions

- So far Context has been overlooked in most Affection Computing researches
- Collaboration among Affection researchers from different disciplines
- Fast real-time processing
- Multimodal detection and recognition to achieve higher accuracy
- On/Off focus
- Systems that can model *conscious* and *subconscious* user behaviour

Rafael A. Calvo, Sidney D'Mello, "Affect Detection: An Interdisciplinary Review of Models, Methods, and Their Applications

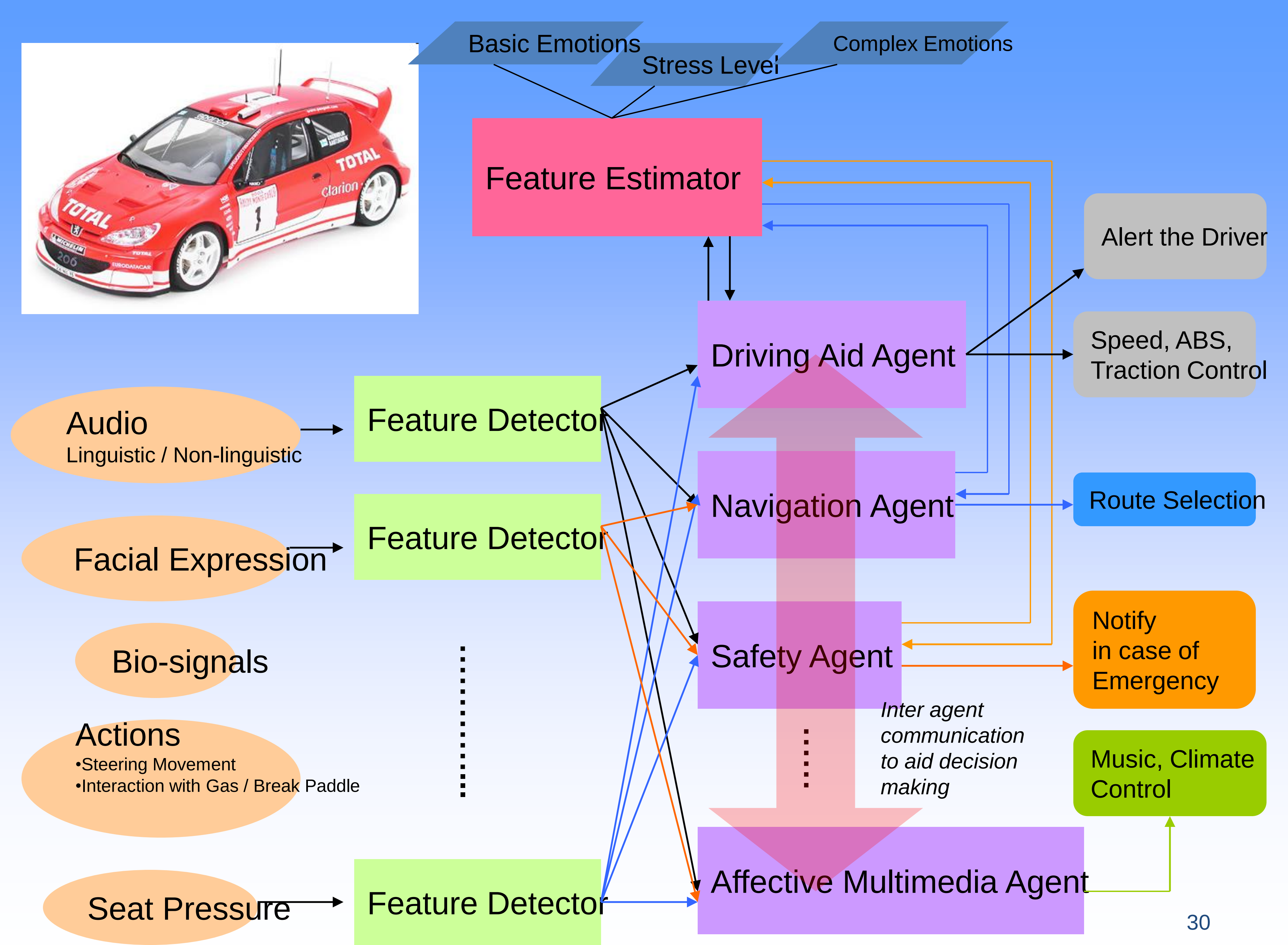
Context Aware Multimodal Affection Analysis Based Smart Learning Environment





Driver Emotion Aware Multiple Agent Controlled Automatic Vehicle

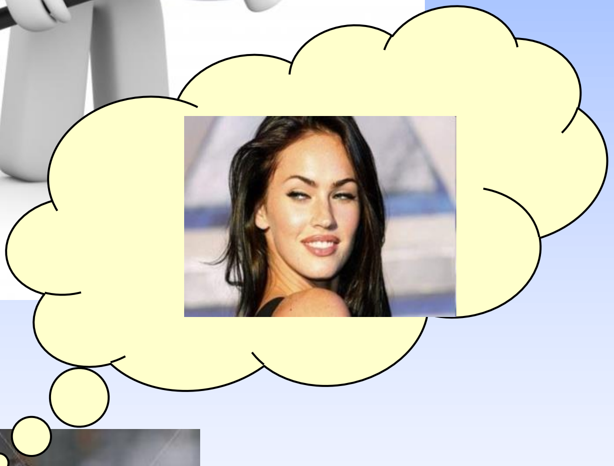



Basic Emotions
Stress Level
Complex Emotions
Feature Estimator
Alert the Driver
Driving Aid Agent
Speed, ABS, Traction Control
Audio
Linguistic / Non-linguistic
Feature Detector
Navigation Agent
Route Selection
Facial Expression
Feature Detector
Safety Agent
Notify in case of Emergency
Bio-signals
Inter agent communication to aid decision making
Actions
•Steering Movement
•Interaction with Gas / Break Paddle
Music, Climate Control
Seat Pressure
Feature Detector
Affective Multimedia Agent

Affective Computing

Concerned Issues

- ☐ Privacy concerns [4] [5]
  - I do not want the outside world to know what goes through my mind…Twitter is the limit
- ☐ Ethical concerns [5]
  - Robot nurse or caregivers capable of effective feedback
- ☐ Risk of misuse of the technology
  - In the hand of impostors
  - Computers start to make *emotionally* distorted, harmful decisions [18]
- ☐ Complex technology
  - Effectiveness is still questionable, risk of false interpretation



Conclusion

Strategic Business Insight (SBI) –

"Ultimately, affective-computing technology could eliminate the need for devices that today stymie and frustrate users…

Affective computing is an important development in computing, because as pervasive or ubiquitous computing becomes mainstream, computers will be far more invisible and natural in their interactions with humans." [4]

Toyota's thought controlled wheelchair [19]

Emotional computer

- https://www.youtube.com/watch?v=whCJ4NLUSB8

- Including facial expression, speech and gesture analysis and facial expression and speech synthesis.

Picard, R. 1995. *Affective Computing*. M.I.T Media Laboratory Perceptual Computing Section Technical Report
Picard, R. 1995. *Affective Computing*. The MIT Press

https://www.youtube.com/watch?v=mSBcG-SStqc

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[20] http://www.w3.org/TR/2009/WD-emotionml-20091029/

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Available biosignal databases

- DEAP (http://www.eecs.qmul.ac.uk/mmv/datasets/deap/)
  - Electroencephalogram (EEG) and peripheral physiological signals (also some facial videos)
- Dimensional annotation (self-report and online ratings)
  - Database descriptions
- http://www.eecs.qmul.ac.uk/mmv/datasets/deap/readme.html
- http://www.eecs.qmul.ac.uk/mmv/datasets/deap/doc/tac_special_issue_2011.pdf

Facial expression tools

- Face detection
  - http://docs.opencv.org/trunk/doc/py_tutorials/py_objdetect/py_face_detection/py_face_detection.html
- Appearance features: LBP/LBP-TOP
  - http://www.cse.oulu.fi/CMV/Downloads/LBPMatlab
- Landmark Detection for geometric features
  - Discriminative Response Map Fitting (DRMF): http://ibug.doc.ic.ac.uk/resources/drmf-matlab-code-cvpr-2013/
  - ASM, AAM

Biosignal tools (GPL licenses)

- EEGLAB
  - Graphical EEG signal processing environment/toolbox for MATLAB
  - http://sccn.ucsd.edu/eeglab/
- BioSig
  - MATLAB Toolbox for biosignal processing, feature extraction etc.
  - http://biosig.sourceforge.net/

Swarms are Powerful!

- Swarms can achieve things no single individual could
  - Don’t believe me? See for yourself:

Foto: Kathy Bishop, morguefile.com

Introduction

Why do animals swarm?

- Defense against predators
  - Enhanced predator detection
  - Minimizing chance of capture
- Enhanced foraging success
- Better chances to find a mate
- Decrease of energy consumption

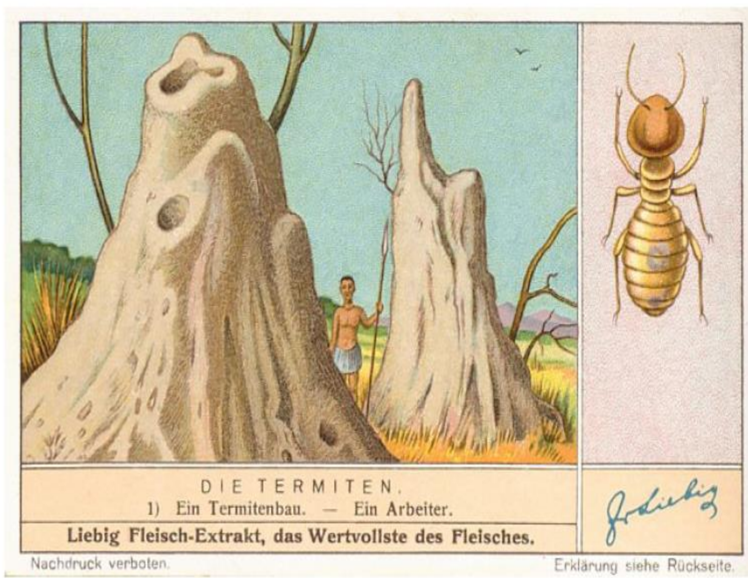
Introduction

Social Insects

- Several million years of success
  - Efficient
  - Flexible
  - Robust
- Solve many Problems:
  - Find food, feed the brood, defend the nest
  - Build a nest …

Social Insects (2)

- Create remarkable structures



Liebig card, 1937, Card set number 1107

Introduction

Powerful … but simple

- All evidence suggests:
  - No central control
  - Only simple rules for each individual
- Emergent phenomena
- Self-organization

Harness this Power out of Simplicity

- Technical systems are getting larger and more complex
  - Global control hard to define and program
  - Larger systems lead to more errors
- Swarm intelligence systems are:
  - Robust
  - Relatively simple (How to program a swarm?)

Definition

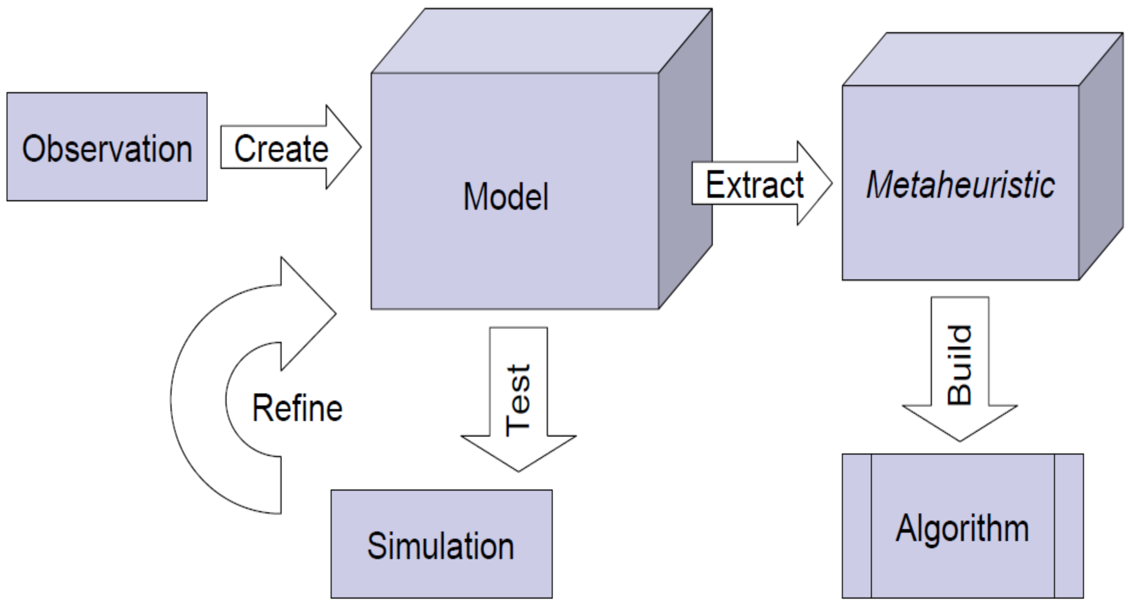
What is “Swarm Intelligence”?

- First used by Beni, Hackwood and Wang for work on cellular robotic systems
- Later for anything swarm inspired:

> “any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies” [Bonabeau, Dorigo, Theraulaz: Swarm Intelligence, p. 7]

Definition

Swarm Intelligence (SI) How-To



Two Common SI Algorithms

- **Ant Colony Optimization**
- Particle Swarm Optimization

Ant Colony Optimization (ACO)

- The study of artificial systems modeled after the behavior of real ant colonies and are useful in solving discrete optimization problems
- Introduced in 1992 by Marco Dorigo
  - Originally called it the Ant System (AS)
  - Has been applied to
    - Traveling Salesman Problem (and other shortest path problems)
    - Several NP-hard Problems
- It is a population-based metaheuristic used to find approximate solutions to difficult optimization problems

What is Metaheuristic?

- "A metaheuristic refers to a master strategy that guides and modifies other heuristics to produce solutions beyond those that are normally generated in a quest for local optimality" – Fred Glover and Manuel Laguna
- Or more simply:
  - It is a set of algorithms used to define heuristic methods that can be used for a large set of problems

Artificial Ants

- A set of software agents
- Stochastic
- Based on the pheromone model
  - Pheromones are used by real ants to mark paths. Ants follow these paths (i.e., trail-following behaviors)
- Incrementally build solutions by moving on a graph
- Constraints of the problem are built into the heuristics of the ants

Using ACO

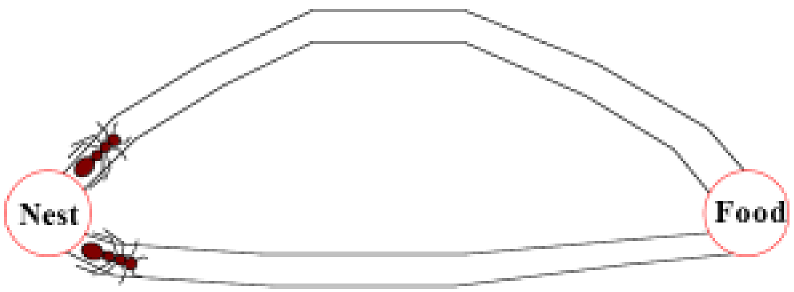
- The optimization problem must be written in the form of a path finding problem with a weighted graph
- The artificial ants search for “good” solutions by moving on the graph
  - Ants can also build infeasible solutions – which could be helpful in solving some optimization problems
- The metaheuristic is constructed using three procedures:
  - ConstructAntsSolutions
  - UpdatePheromones
  - DaemonActions

ConstructAntsSolutions

- Manages the colony of ants
- Ants move to neighboring nodes of the graph
- Moves are determined by stochastic local decision policies based on pheromone tails and heuristic information
- Evaluates the current partial solution to determine the quantity of pheromones the ants should deposit at a given node

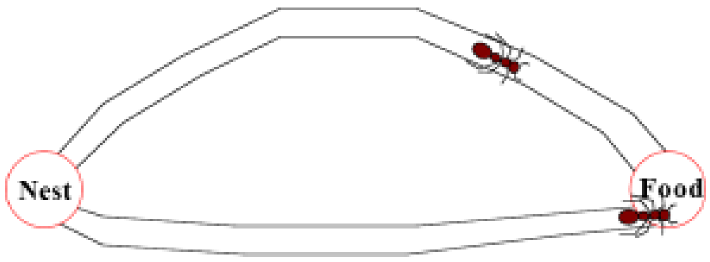
Ant foraging

Cooperative search by pheromone trails



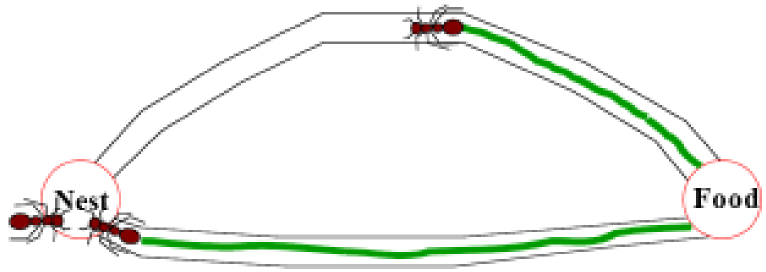
Ant foraging

Cooperative search by pheromone trails



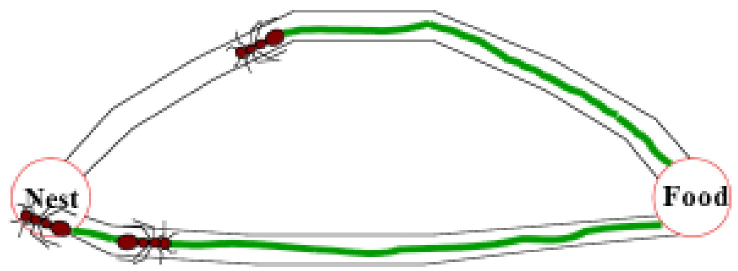
Ant foraging

Cooperative search by pheromone trails



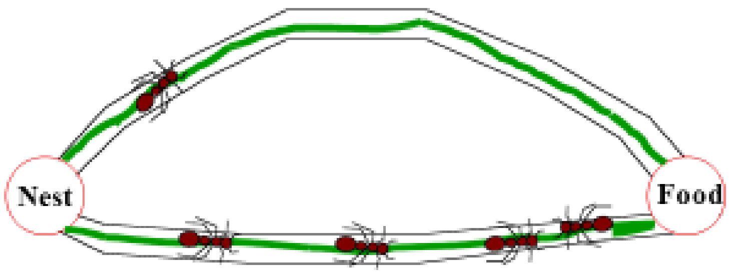
Ant foraging

Cooperative search by pheromone trails



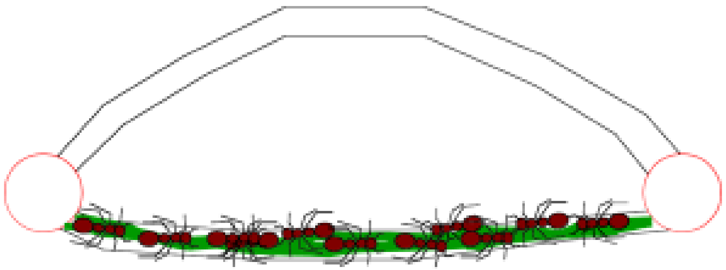
Ant foraging

Cooperative search by pheromone trails



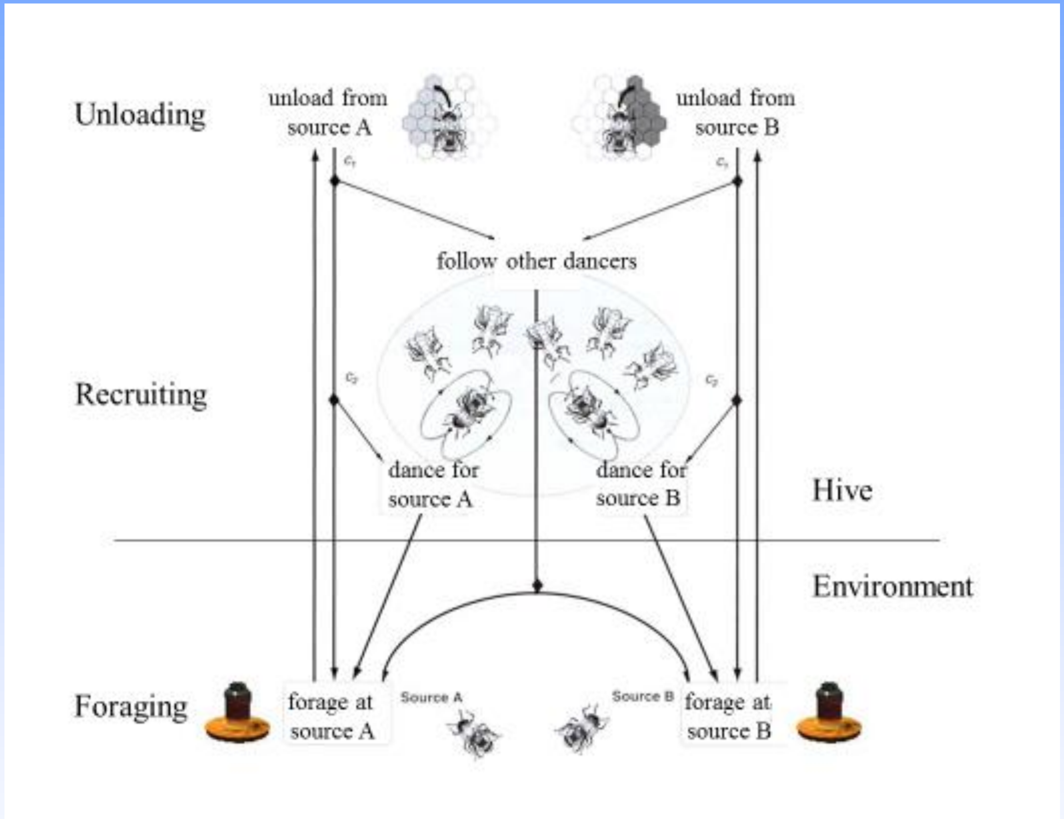
Ant foraging

Cooperative search by pheromone trails



Characteristics of self-organized systems

- structure emerging from a homogeneous startup state
- multistability - coexistence of many stable states
- state transitions with a dramatical change of the system behaviour



Unloading
unload from source A
unload from source B
follow other dancers
Recruiting
dance for source A
dance for source B
Hive
Environment
Foraging
forage at source A
Source A
Source B
forage at source B

Two Common SI Algorithms

- Ant Colony Optimization
- **Particle Swarm Optimization**

Particle Swarm Optimization (PSO)

- A population based stochastic optimization technique
- Searches for an optimal solution in the computable search space
- Developed in 1995 by Dr. Eberhart and Dr. Kennedy
- Inspiration: Swarms of Bees, Flocks of Birds, Schools of Fish

Model

An example: Bird flocking

- “Boids” model created by Rynolds in 1987
  - Boids = “bird-oid” objects (also schooling fish)
- Model: biologically and physically sound
  - Individual has only local knowledge
  - Has certain cognitive capabilities
  - Is bound by the laws of physic
- Only three simple rules …

The basic idea

- Each particle is searching for the optimum
- Each particle is *moving* and hence has a *velocity*.
- Each particle remembers the position it was in where it had its best result so far (its *personal best*)
- *But this would not be much good on its own; particles need help in figuring out where to search.*

The basic idea II

- The particles in the swarm *co-operate*. They exchange information about what they've discovered in the places they have visited
- The co-operation is very simple. In basic PSO it is like this:
  - A particle has a *neighbourhood* associated with it.
  - A particle knows the fitnesses of those in its neighbourhood, and uses the *position* of the one with best fitness.
  - This position is simply used to adjust the particle's velocity

The Particle Swarm Optimization Algorithm

Decision Support
2010-2011

Andry Pinto
Hugo Alves
Inês Domingues
Luís Rocha
Susana Cruz

Summary

- Introduction to Particle Swarm Optimization (PSO)
  - Origins
  - Concept
  - PSO Algorithm

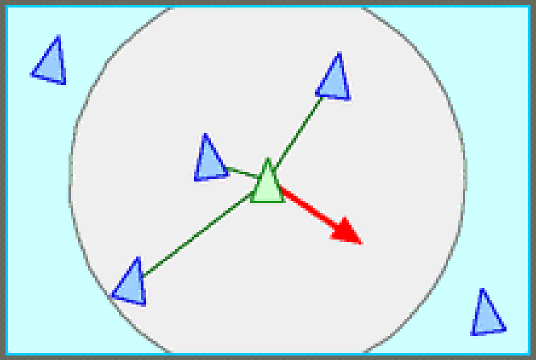
- PSO for the Bin Packing Problem (BPP)
  - Problem Formulation
  - Algorithm
  - Simulation Results

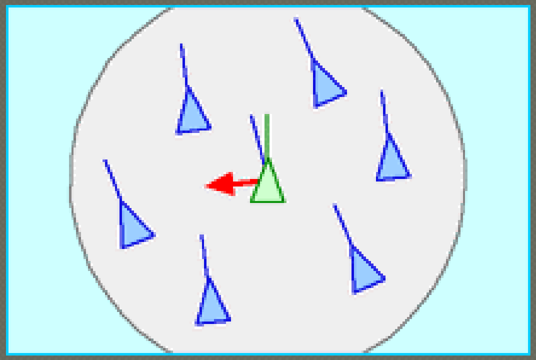
Introduction to the PSO: **Origins**

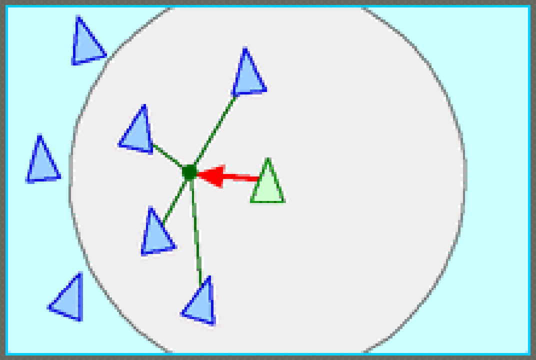
- Inspired from the nature social behavior and dynamic movements with communications of insects, birds and fish

Introduction to the PSO: **<u>Origins</u>**

- In 1986, Craig Reynolds described this process in 3 simple behaviors:







<u>Separation</u>

avoid crowding local flockmates

<u>Alignment</u>

move towards the average heading of local flockmates

<u>Cohesion</u>

move toward the average position of local flockmates

Introduction to the PSO: **Origins**

- Application to optimization: Particle Swarm Optimization
- Proposed by James Kennedy & Russell Eberhart (1995)
- Combines self-experiences with social experiences

Introduction to the PSO: <u>**Concept**</u>

- Uses a number of agents (**particles**) that constitute a swarm moving around in the search space looking for the best solution

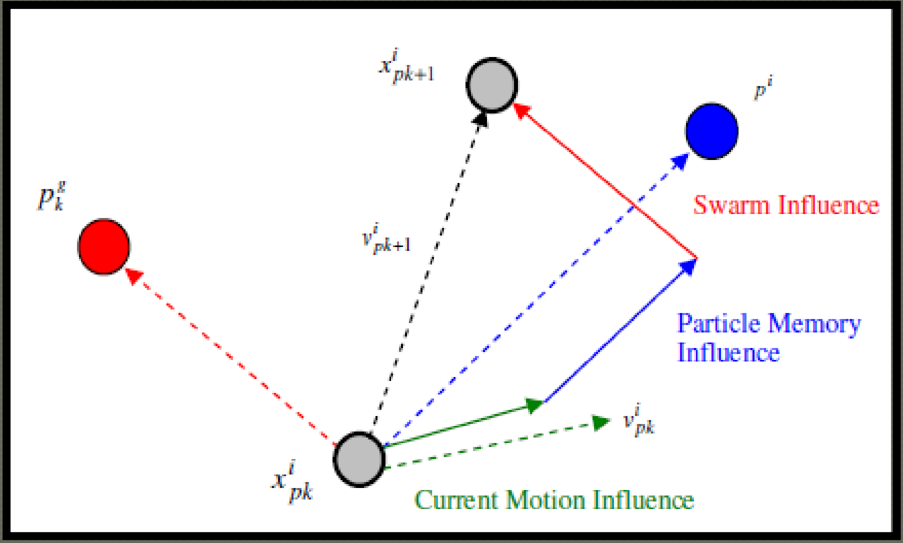
- Each particle in search space adjusts its "flying" according to its own flying experience as well as the flying experience of other particles

Introduction to the PSO: <u>**Concept**</u>

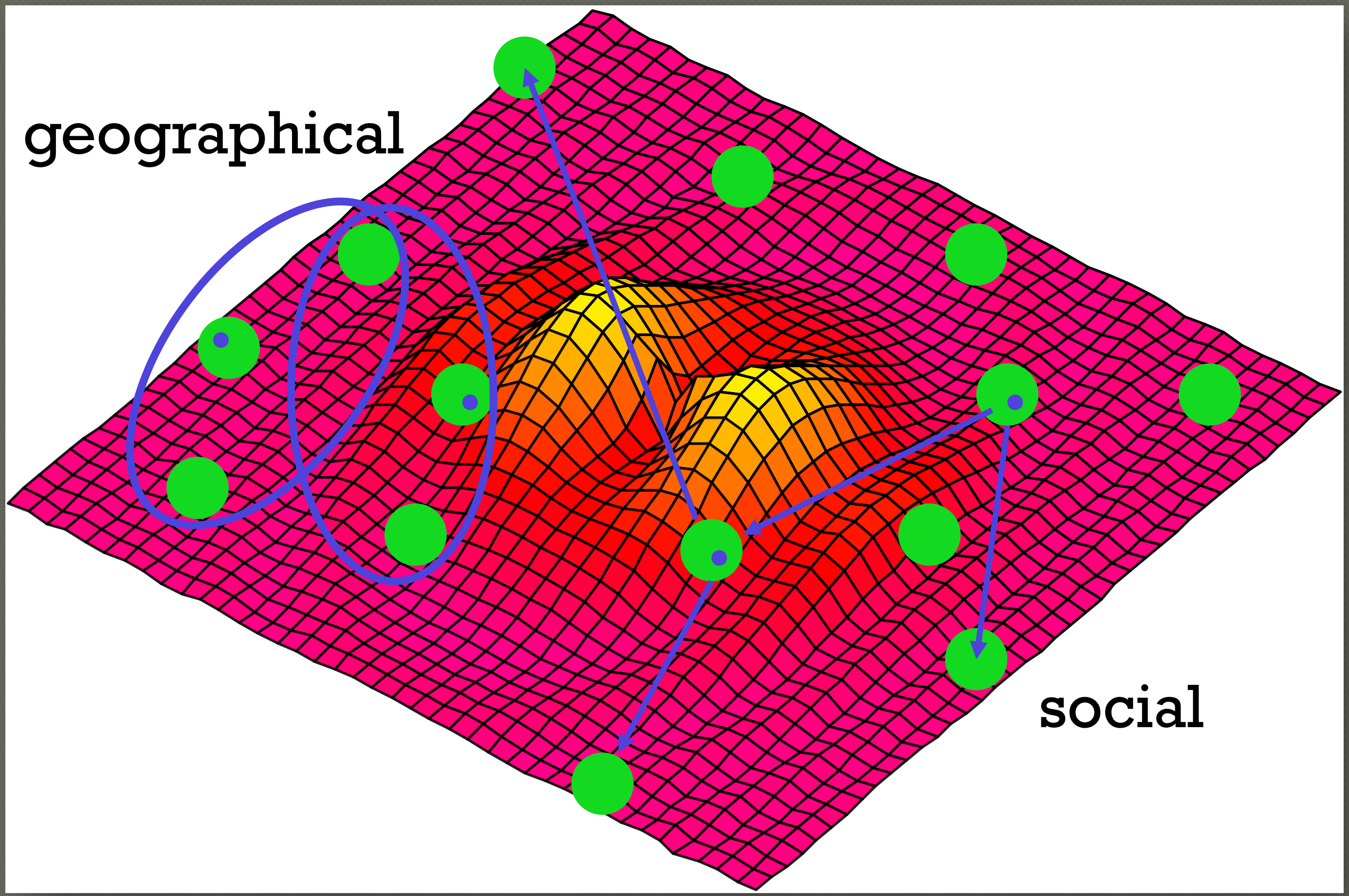
- Collection of flying particles (swarm) - Changing solutions
- Search area - Possible solutions
- Movement towards a promising area to get the global optimum
- Each particle keeps track:
  - its best solution, personal best, *<u>pbest</u>*
  - the best value of any particle, global best, *<u>gbest</u>*

Introduction to the PSO: Concept

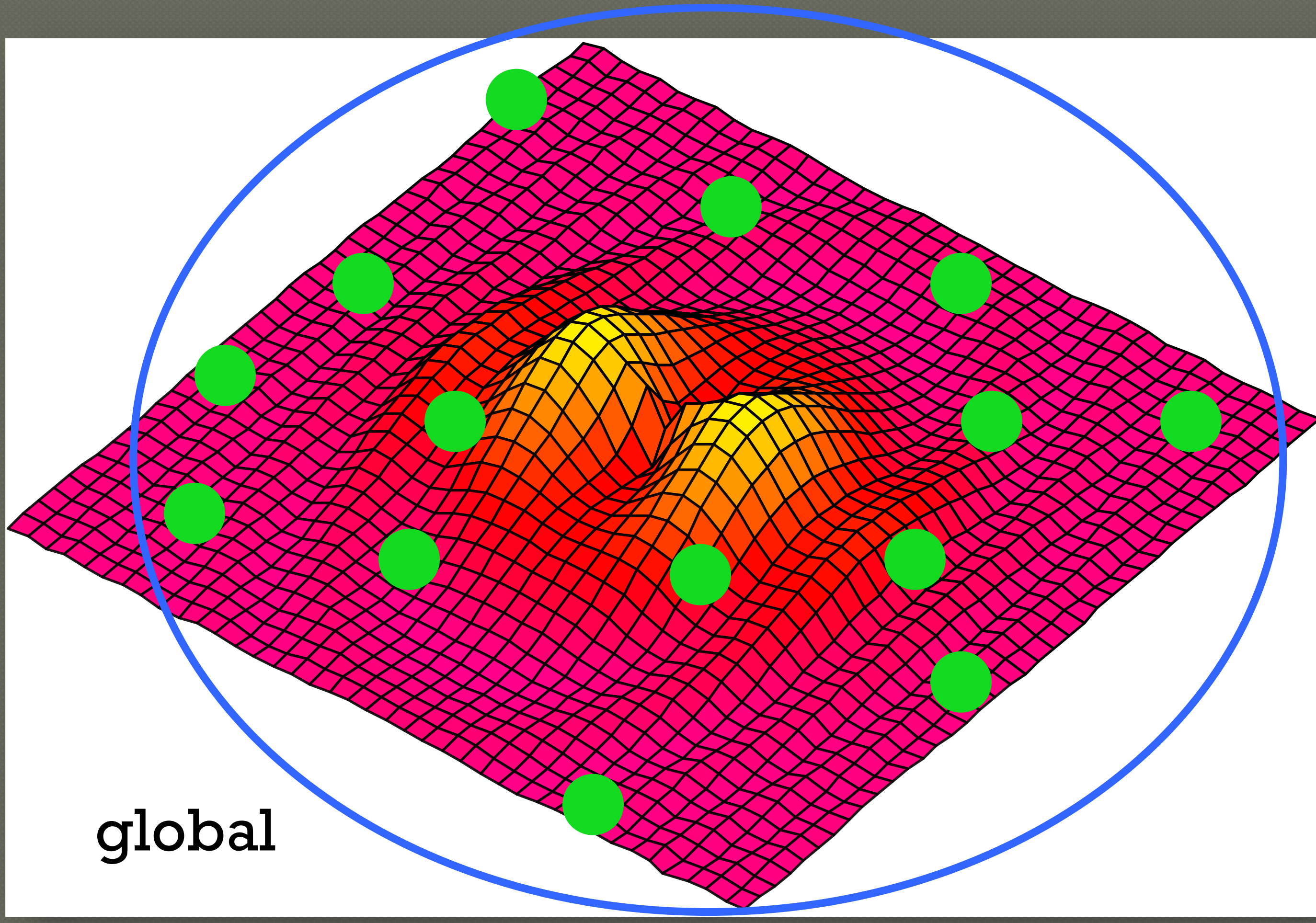
- Each particle adjusts its travelling speed dynamically corresponding to the flying experiences of itself and its colleagues
- Each particle modifies its position according to:
  - its current position
  - its current velocity
  - the distance between its current position and *pbest*
  - the distance between its current position and *gbest*



Introduction to the PSO: **Algorithm - Neighborhood**



Introduction to the PSO: **Algorithm - Neighborhood**



Introduction to the PSO: **Algorithm - Parameterss**

- Algorithm parameters
  - $\boldsymbol{A}$: Population of agents
  - $\boldsymbol{p_i}$: Position of agent $\boldsymbol{a_i}$ in the solution space
  - $\boldsymbol{f}$: Objective function
  - $\boldsymbol{v_i}$: Velocity of agent's $\boldsymbol{a_i}$
  - $\boldsymbol{V(a_i)}$: Neighborhood of agent a_i (fixed)
- The neighborhood concept in PSO is not the same as the one used in other meta-heuristics search, since in PSO each particle's neighborhood never changes (is fixed)

Introduction to the PSO: **Algorithm**

```
[x*] = PSO()
P = Particle_Initialization();
For i=1 to it_max
   For each particle p in P do
      fp = f(p);
      If fp is better than f(pBest)
            pBest = p;
      end
   end
   gBest = best p in P;
   For each particle p in P do
        v = v + c1*rand*(pBest – p) + c2*rand*(gBest – p);
        p = p + v;
   end
end
```

Introduction to the PSO: Algorithm

- Particle update rule

$$p = p + v$$

  - with

$$v = v + c_1 * rand * (pBest - p) + c_2 * rand * (gBest - p)$$

  - where

- *p*: particle's position
- *v*: path direction
- c_1: weight of local information
- c_2: weight of global information
- *pBest*: best position of the particle
- *gBest*: best position of the swarm
- *rand*: random variable

Introduction to the PSO: Algorithm - Parameters

- Number of particles usually between 10 and 50
- C_1 is the importance of personal best value
- C_2 is the importance of neighborhood best value
- Usually $C_1 + C_2 = 4$ (empirically chosen value)
- If velocity is too low → algorithm too slow
- If velocity is too high → algorithm too unstable

Introduction to the PSO: **Algorithm**

1. Create a ‘population’ of agents (particles) uniformly distributed over X
2. Evaluate each particle’s position according to the objective function
3. If a particle’s current position is better than its previous best position, update it
4. Determine the best particle (according to the particle’s previous best positions)

Introduction to the PSO: **Algorithm**

5. Update particles' velocities:

$$\mathbf{v}_i^{t+1} = \underbrace{\mathbf{v}_i^{t}}_{inertia} + \underbrace{c_1 \mathbf{U}_1^{t}(\mathbf{pb}_i^{t} - \mathbf{p}_i^{t})}_{personal\ influence} + \underbrace{c_2 \mathbf{U}_2^{t}(\mathbf{gb}^{t} - \mathbf{p}_i^{t})}_{social\ influence}$$

6. Move particles to their new positions:

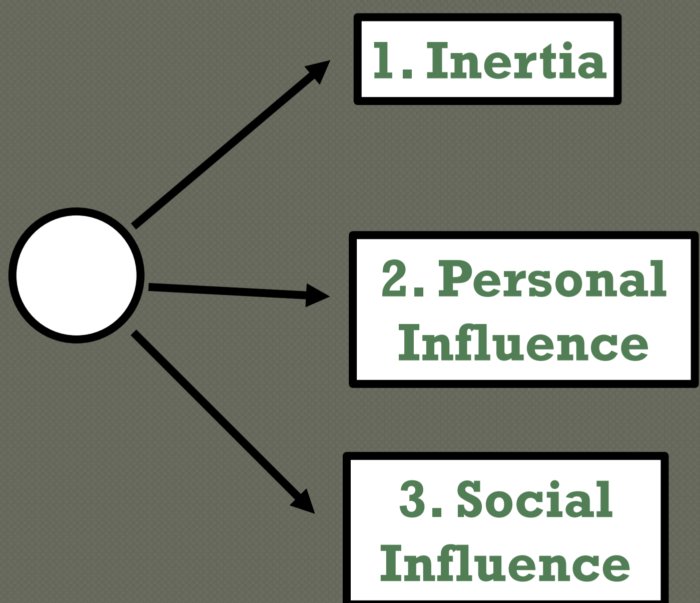
$$\mathbf{p}_i^{t+1} = \mathbf{p}_i^{t} + \mathbf{v}_i^{t+1}$$

7. Go to step 2 until stopping criteria are satisfied

Introduction to the PSO: **Algorithm**

Particle's velocity:

$$\mathbf{v}_i^{t+1} = \underbrace{\mathbf{v}_i^t}_{\textit{inertia}} + \underbrace{c_1 \mathbf{U}_1^t (\mathbf{pb}_i^t - \mathbf{p}_i^t)}_{\textit{personal influence}} + \underbrace{c_2 \mathbf{U}_2^t (\mathbf{gb}^t - \mathbf{p}_i^t)}_{\textit{social influence}}$$



- Makes the particle move in the same direction and with the same velocity

- Improves the individual
- Makes the particle return to a previous position, better than the current
- Conservative

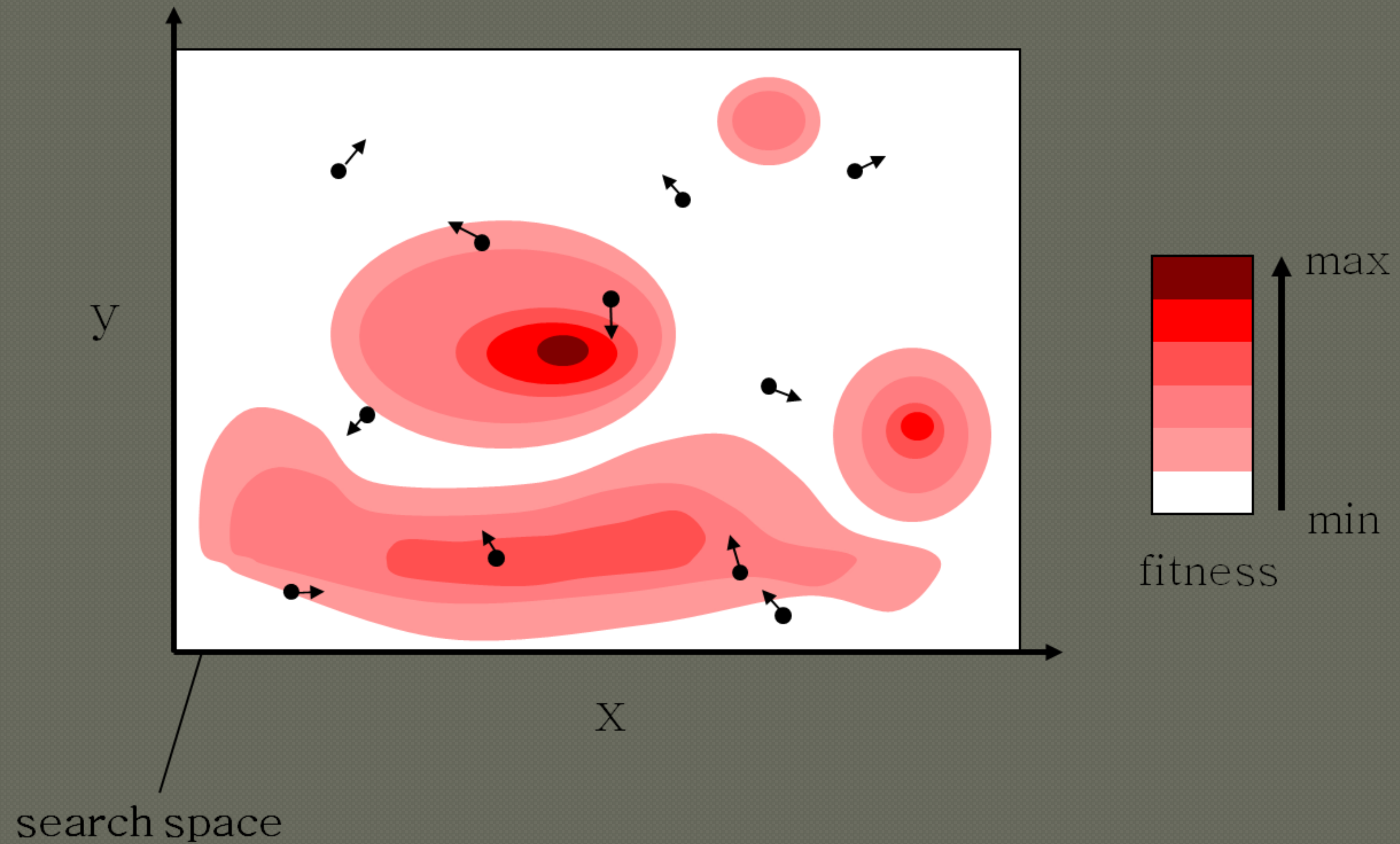
- Makes the particle follow the best neighbors direction

Introduction to the PSO: **Algorithm**

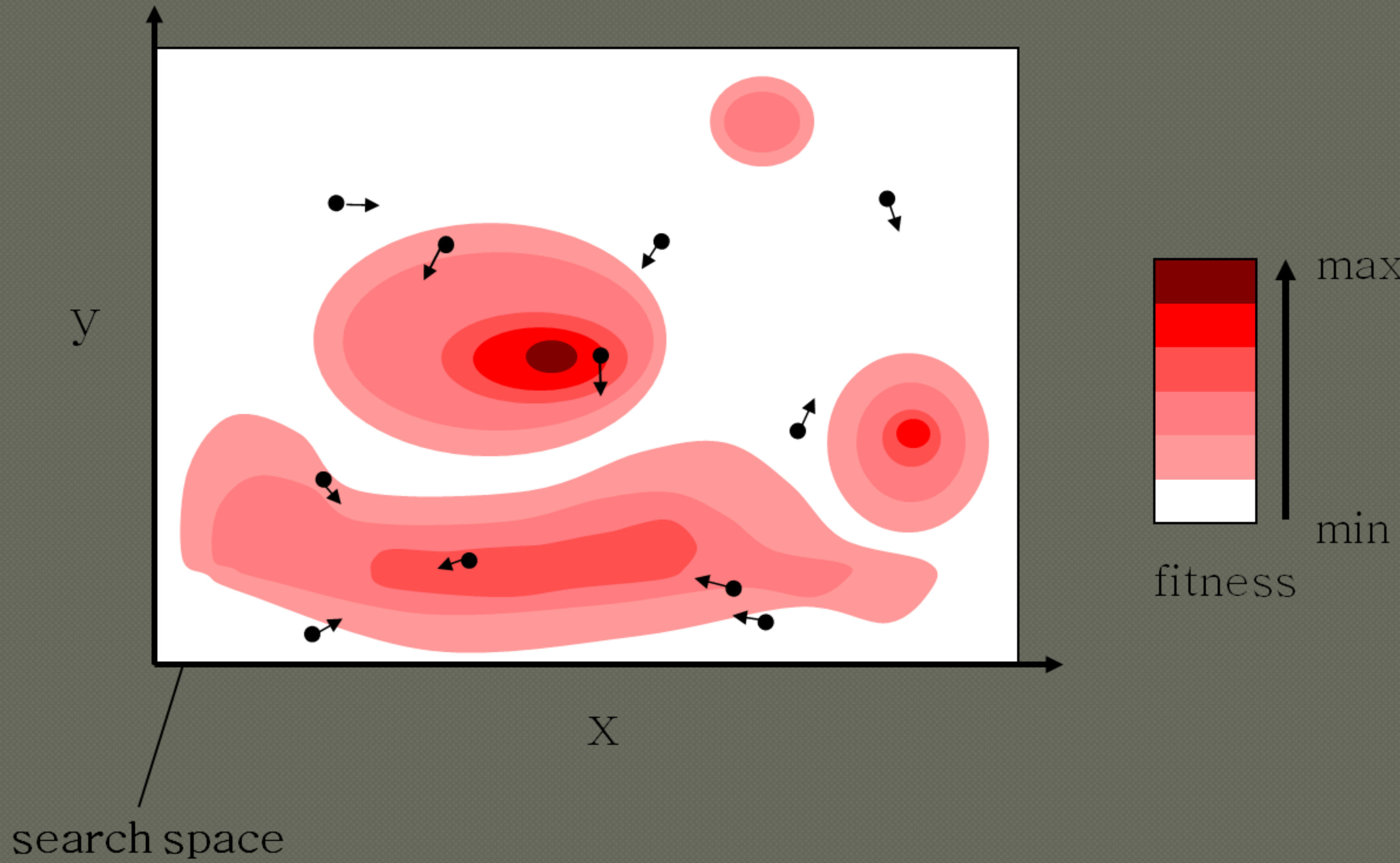
- Intensification: explores the previous solutions, finds the best solution of a given region
- Diversification: searches new solutions, finds the regions with potentially the best solutions
- In PSO:

$$\mathbf{v}_i^{t+1} = \underbrace{\mathbf{v}_i^{t}}_{\textbf{Diversification}} + \underbrace{c_1 \mathbf{U}_1^t (\mathbf{pb}_i^t - \mathbf{p}_i^t) + c_2 \mathbf{U}_2^t (\mathbf{gb}^t - \mathbf{p}_i^t)}_{\textbf{Intensification}}$$

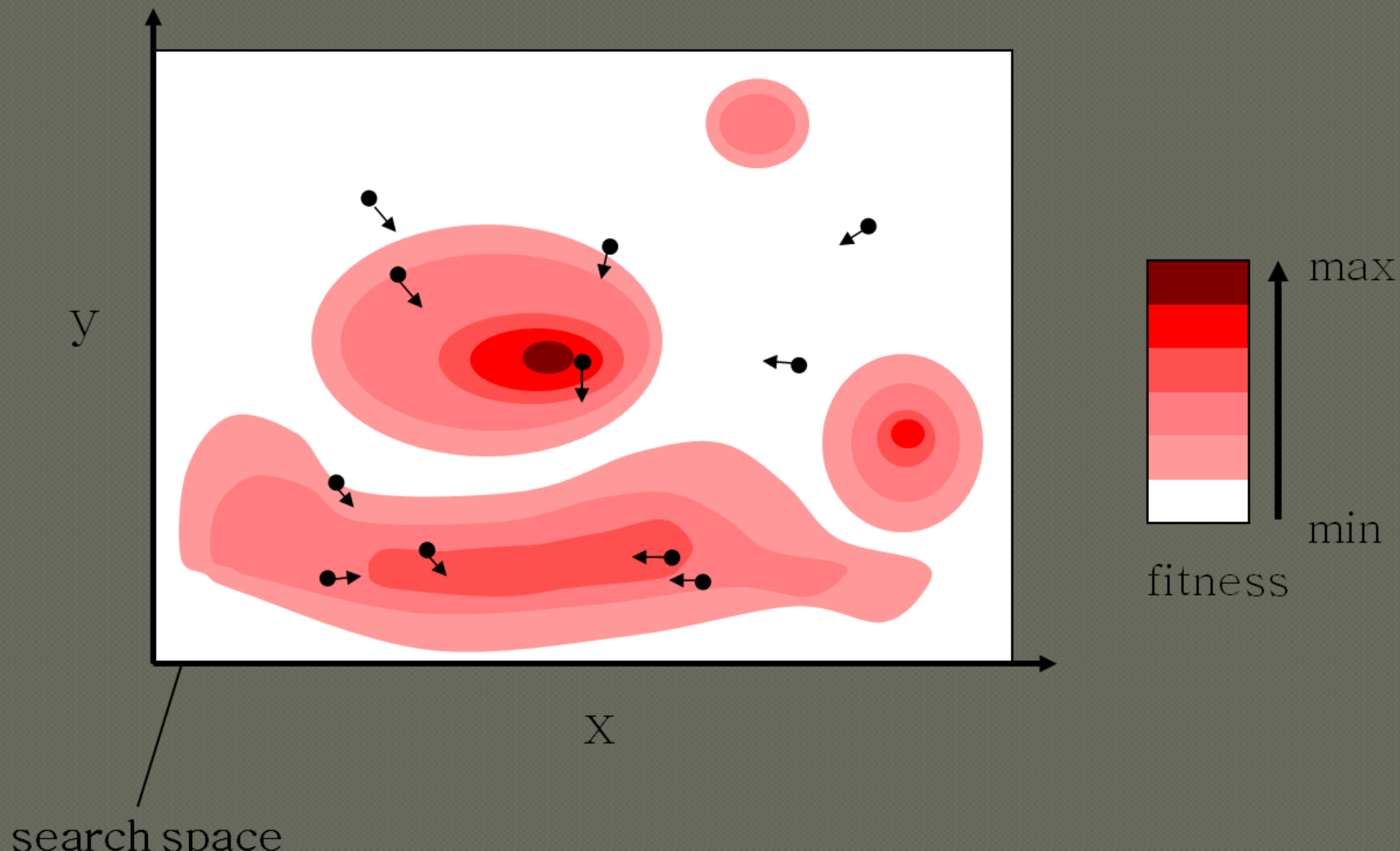
Introduction to the PSO: **Algorithm - Example**



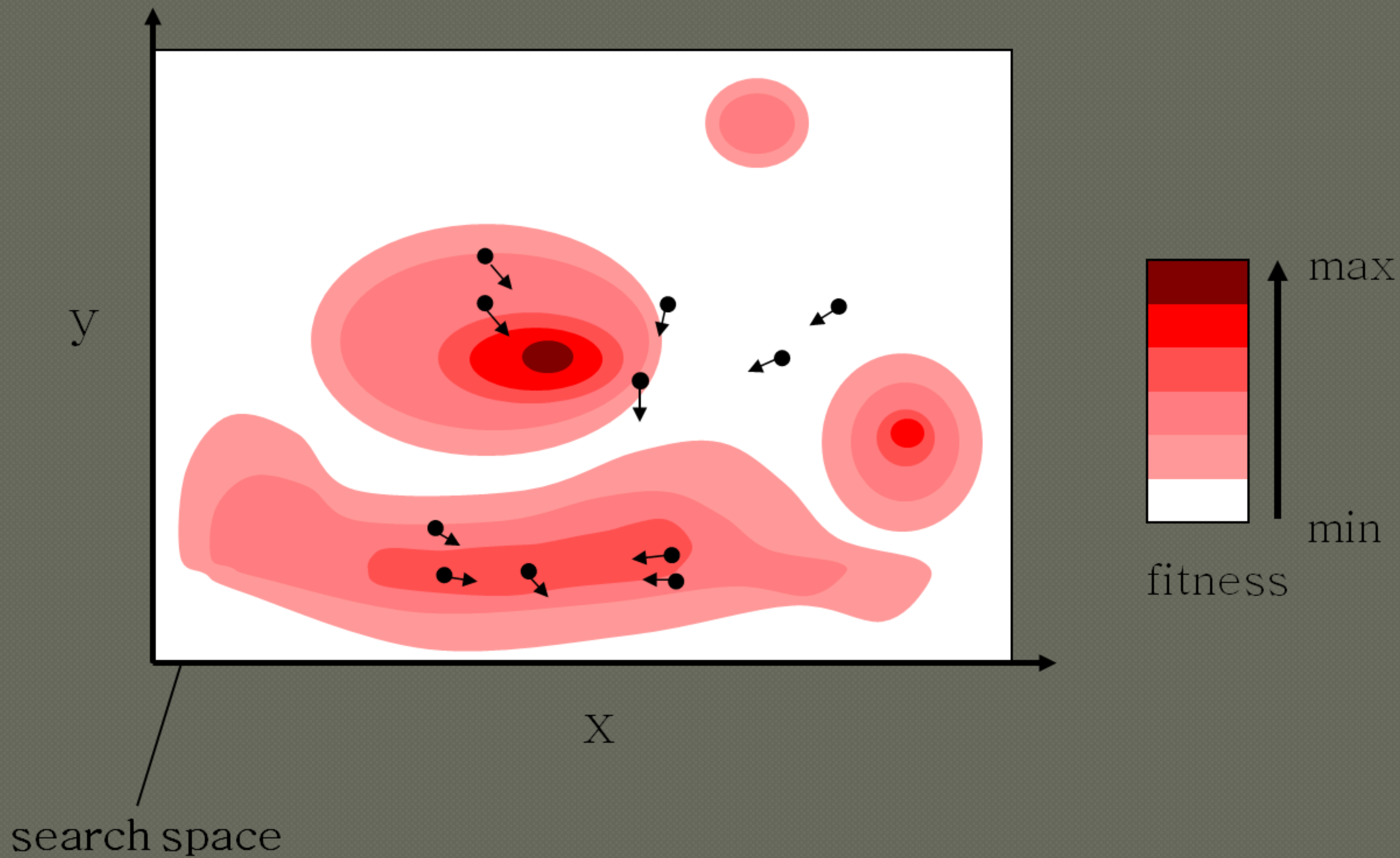
Introduction to the PSO: **Algorithm - Example**



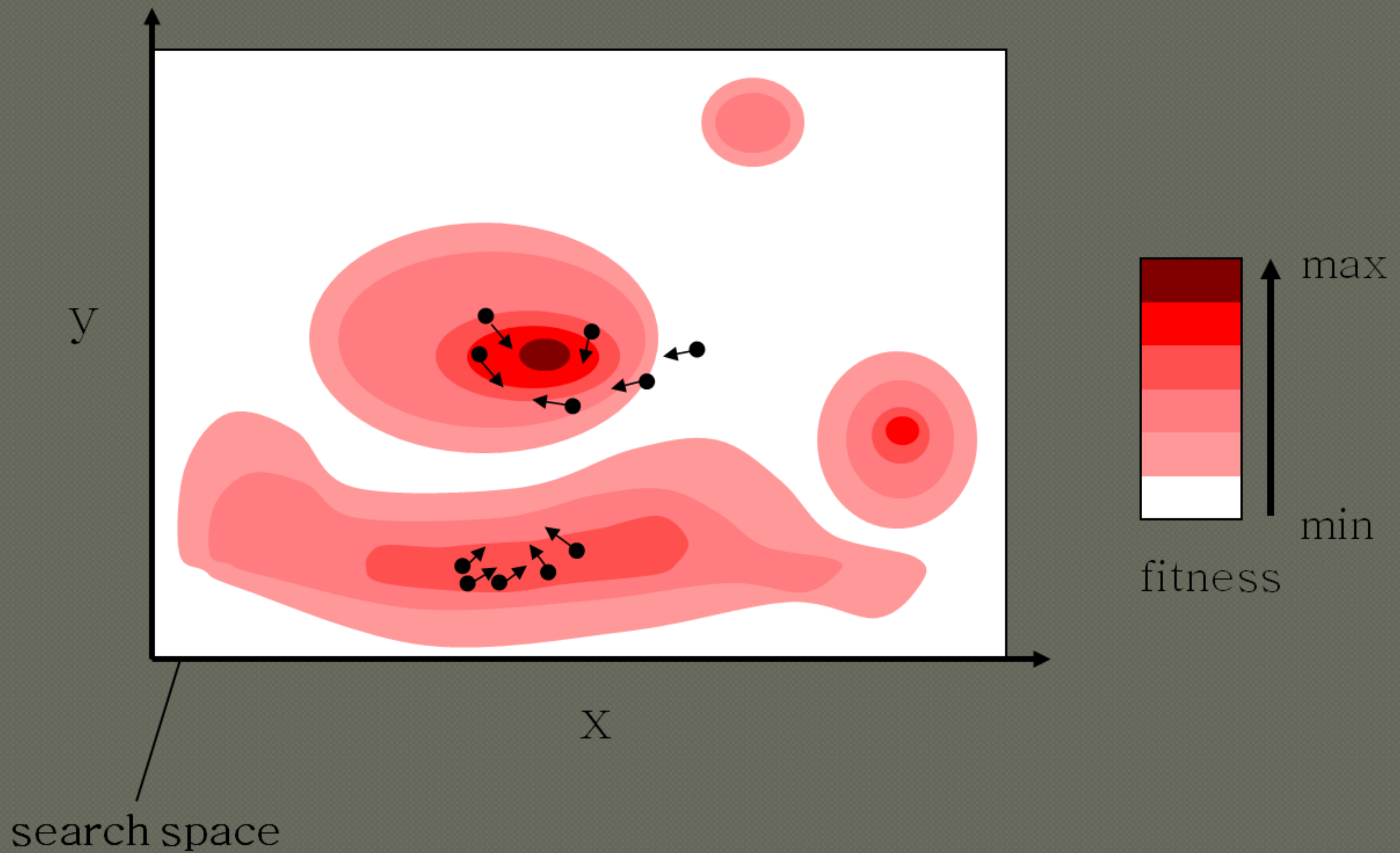
Introduction to the PSO: <u>Algorithm - Example</u>



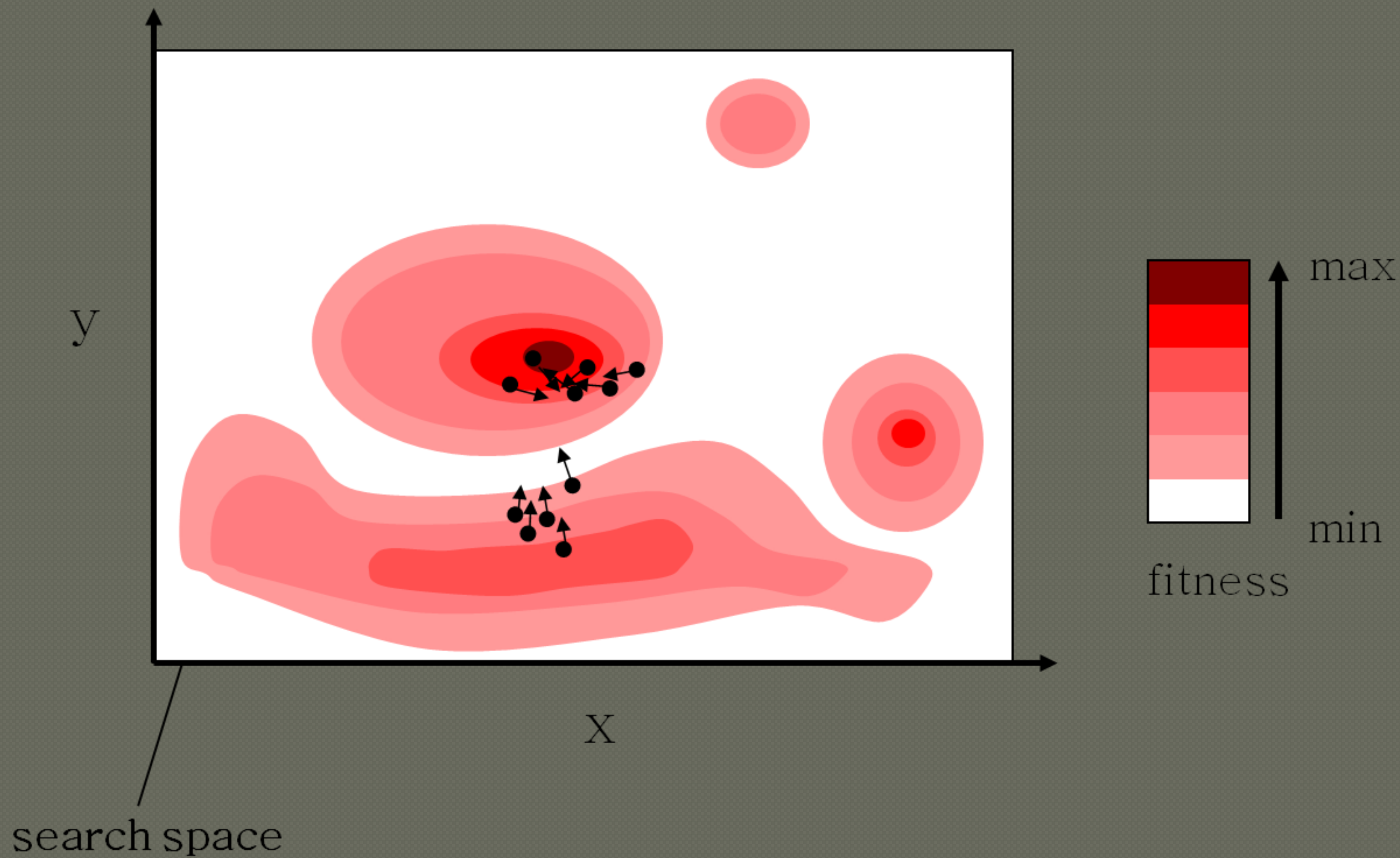
Introduction to the PSO: **Algorithm - Example**



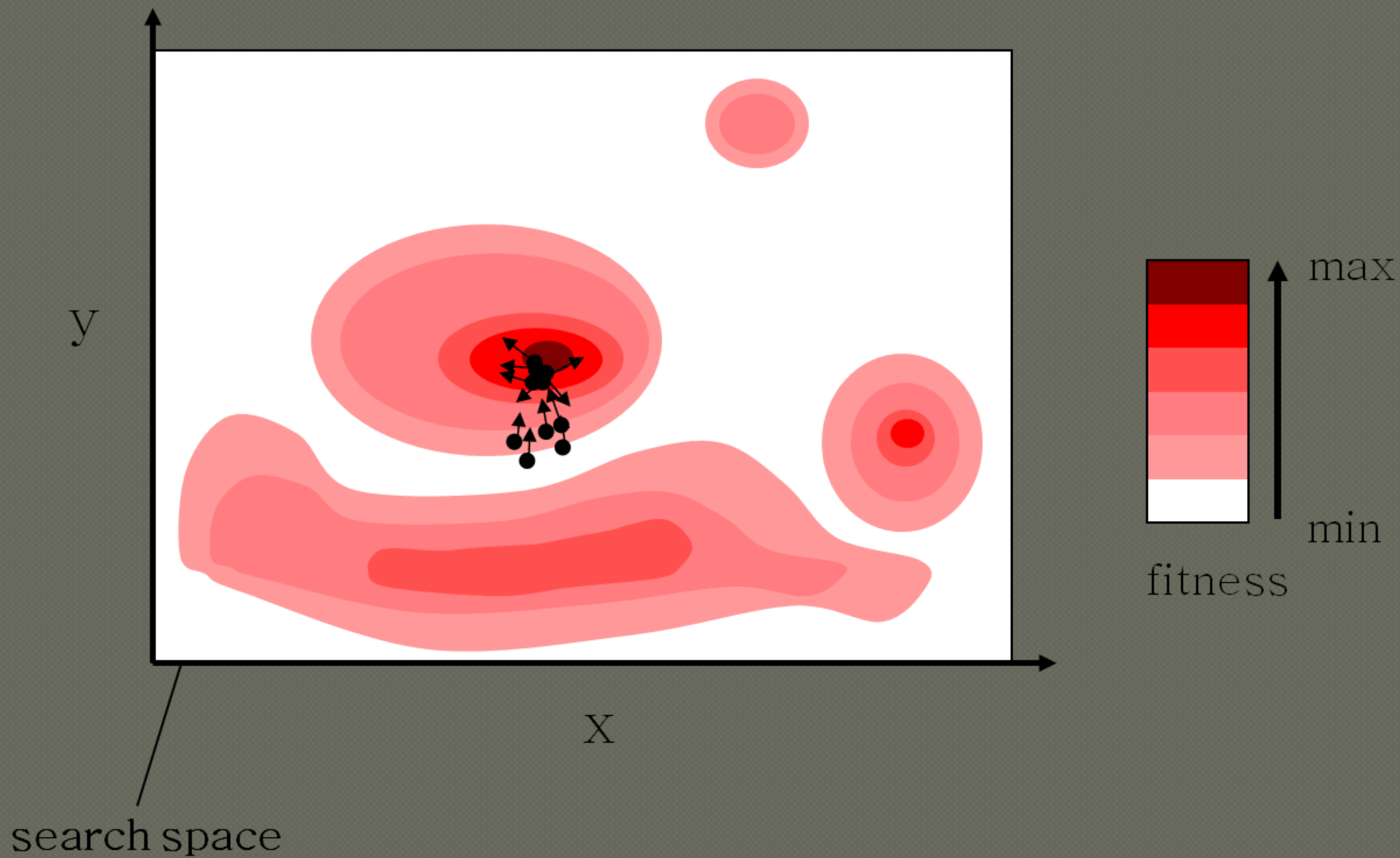
Introduction to the PSO: **Algorithm - Example**



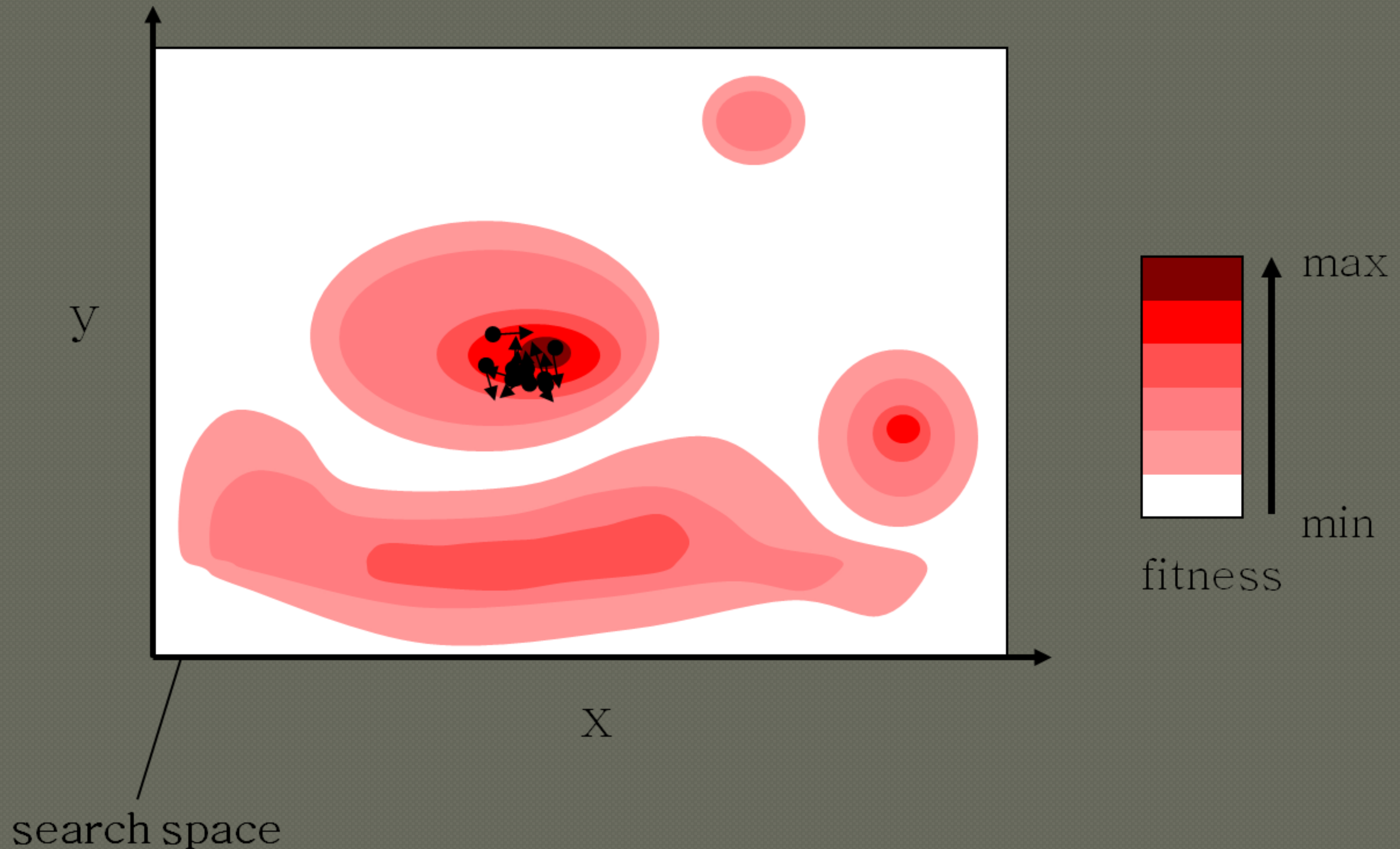
Introduction to the PSO: **Algorithm - Example**



Introduction to the PSO: **Algorithm - Example**



Introduction to the PSO: **Algorithm - Example**



Introduction to the PSO: **Algorithm Characteristics**

- **Advantages**
  - Insensitive to scaling of design variables
  - Simple implementation
  - Easily parallelized for concurrent processing
  - Derivative free
  - Very few algorithm parameters
  - Very efficient global search algorithm
- **Disadvantages**
  - Tendency to a fast and premature convergence in mid optimum points
  - Slow convergence in refined search stage (weak local search ability)

Introduction to the PSO: **Different Approaches**

- **Several approaches**
  - *2-D Otsu PSO*
  - *Active Target PSO*
  - *Adaptive PSO*
  - *Adaptive Mutation PSO*
  - *Adaptive PSO Guided by Acceleration Information*
  - *Attractive Repulsive Particle Swarm Optimization*
  - *Binary PSO*
  - *Cooperative Multiple PSO*
  - *Dynamic and Adjustable PSO*
  - *Extended Particle Swarms*
  - *…*

Davoud Sedighizadeh and Ellips Masehian, "Particle Swarm Optimization Methods, Taxonomy and Applications". International Journal of Computer Theory and Engineering, Vol. 1, No. 5, December 2009

What else?

Other uses of Swarm Intelligence

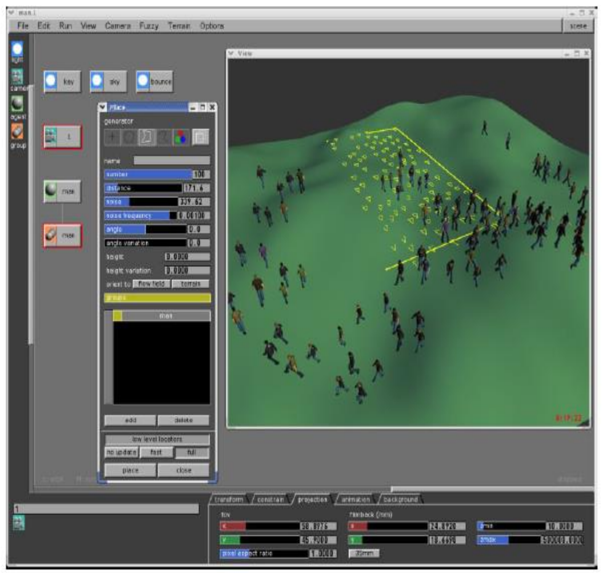
- Swarm robotics (e.g.: Swarm-bots)

Swarm-bots, Marco Dorigo, 2005

What else?

Other uses of Swarm Intelligence (2)

- Art (Lord of the Rings)



Massive, Massive Software

PSO for the BPP: **Introduction**

On solving Multiobjective Bin Packing Problem Using Particle Swarm Optimization

D.S Liu, K.C. Tan, C.K. Goh and W.K. Ho
2006 - IEEE Congress on Evolutionary Computation

- First implementation of PSO for BPP

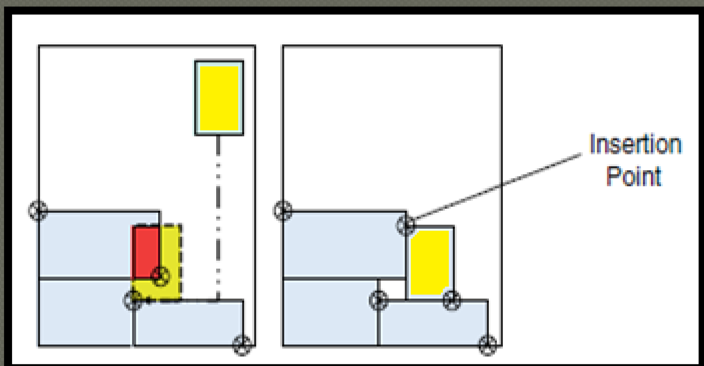
PSO for the BPP: **Problem Formulation**

- Multi-Objective 2D BPP
- Maximum of I bins with width W and height H
- J items with $w_j \leq W, h_j \leq H$ and weight ψ_j
- Objectives
  - Minimize the number of bins used K
  - Minimize the average deviation between the overall centre of gravity and the desired one

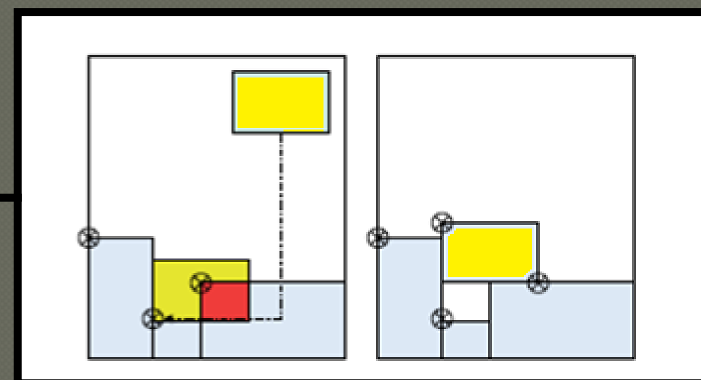
PSO for the BPP: <u>Initialization</u>

- Usually generated randomly
- In this work:
  - Solution from Bottom Left Fill (BLF) heuristic
  - To sort the rectangles for BLF:
    - Random
    - According to a criteria (width, weight, area, perimeter..)

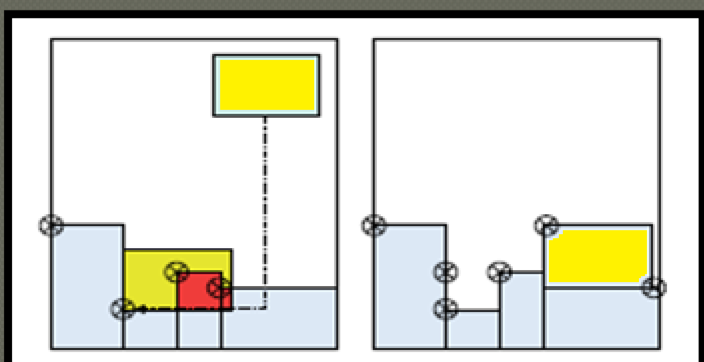
PSO for the BPP: Initialization BLF



Item moved to the right if intersection detected at the top



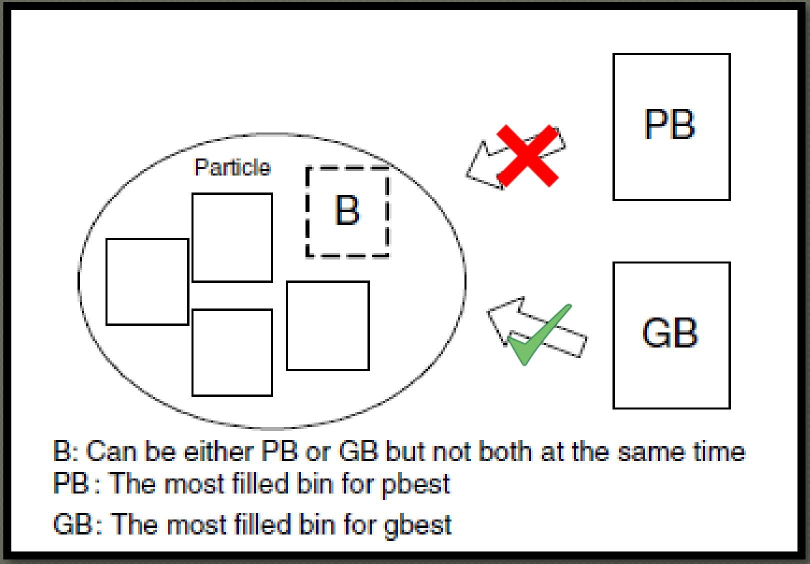
Item moved to the top if intersection detected at the right



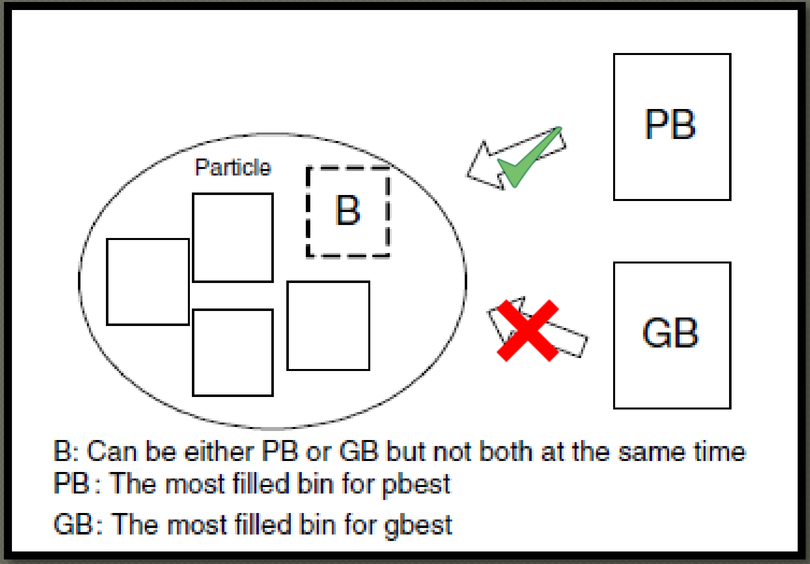
Item moved if there is a lower available space for insertion

PSO for the BPP: **Algorithm**

- Velocity depends on either *pbest* **or** *gbest*: never both at the same time



OR



PSO for the BPP: Algorithm

1st Stage:

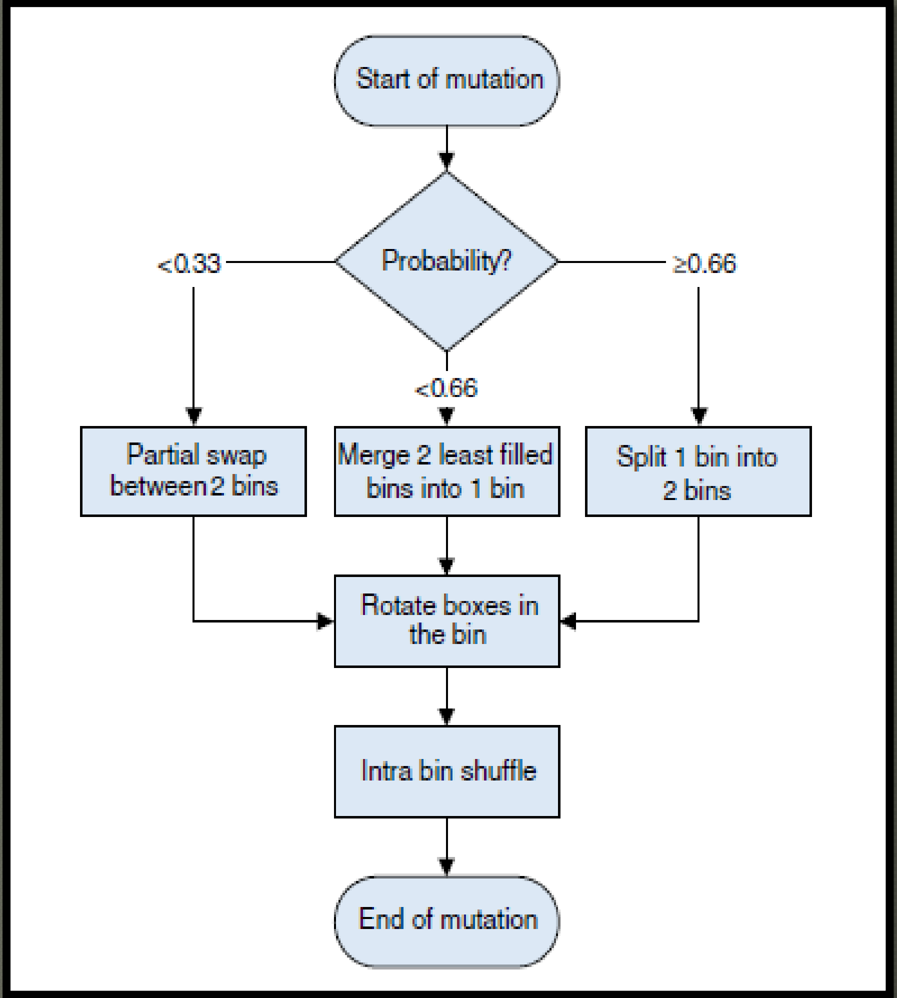
- Partial Swap between 2 bins
- Merge 2 bins
- Split 1 bin

2nd Stage:

- Random rotation

3rd Stage:

- Random shuffle



Mutation modes for a single particle

PSO for the BPP: Algorithm

H hybrid

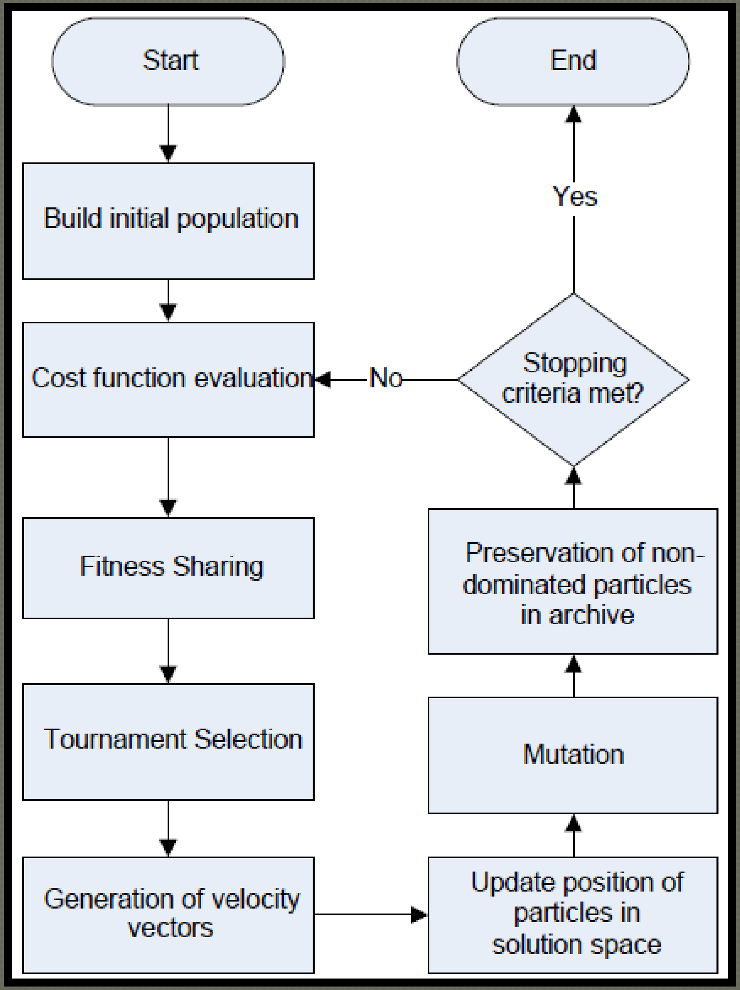
M multi

O objective

P particle

S swarm

O optimization



The flowchart of HMOPSO

PSO for the BPP: Problem Formulation

- 6 classes with 20 instances randomly generated
- Size range:
  - Class 1: [0, 100]
  - Class 2: [0, 25]
  - Class 3: [0, 50]
  - Class 4: [0, 75]
  - Class 5: [25, 75]
  - Class 6: [25, 50]
- Class 2: small items → more difficult to pack

PSO for the BPP: <u>Simulation Results</u>

- Comparison with 2 other methods
  - MOPSO (Multiobjective PSO) from [1]
  - MOEA (Multiobjective Evolutionary Algorithm) from [2]
- Definition of parameters:

Parameter	MOPSO	MOEA	HMOPSO
crossover rate	-	0.7	-
PSO update rate	-	-	0.7
mutation rate	-	0.4	0.4
population size	500	500	500
generation size	200 generations		
niche radius	0.1	0.1	0.1

[1] Wang, K. P., Huang, L., Zhou C. G. and Pang, W., "Particle Swarm Optimization for Traveling Salesman Problem," *International Conference on Machine Learning and Cybernetics, vol. 3, pp.* 1583-1585, 2003.

[2] Tan, K. C., Lee, T. H., Chew, Y. H., and Lee, L. H., "A hybrid multiobjective evolutionary algorithm for solving truck and trailer vehicle routing problems," *IEEE Congress on Evolutionary Computation, vol. 3, pp. 2134-2141, 2003.*

PSO for the BPP: **Simulation Results**

- Comparison on the performance of metaheuristic algorithms against the branch and bound method (BB) on single objective BPP
- Results for each algorithm in 10 runs
- Proposed method (HMOPSO) capable of evolving more optimal solution as compared to BB in 5 out of 6 classes of test instances

PSO for the BPP: Simulation Results

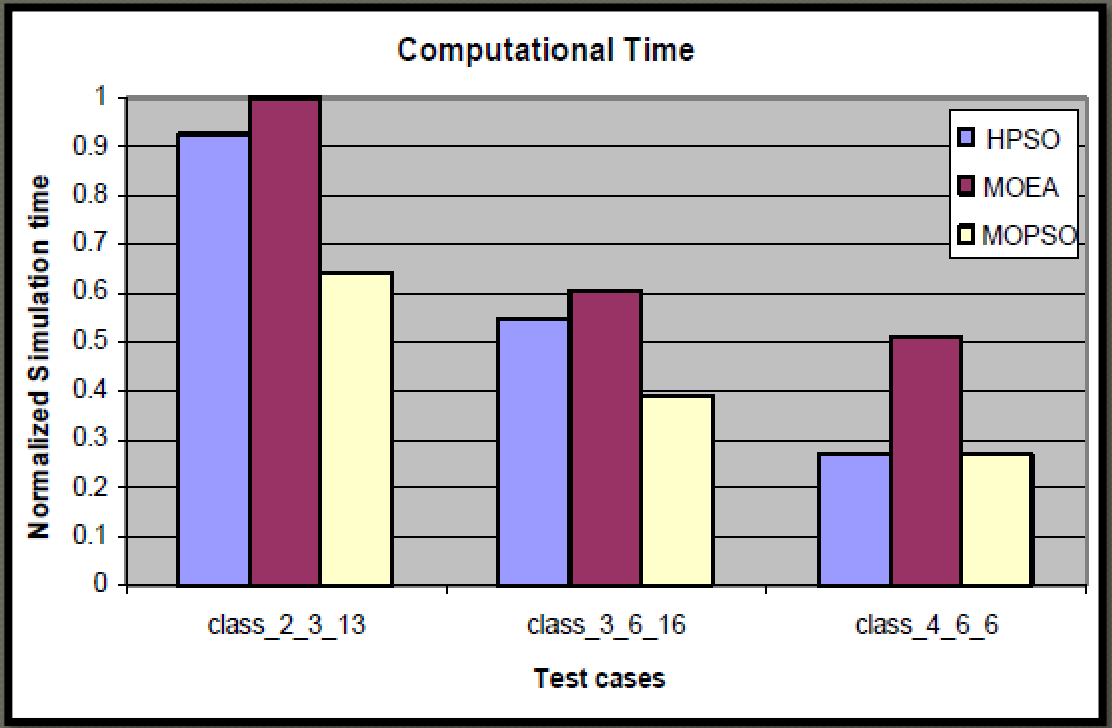
Class 1	BB	MOEA	MOPSO	HMOPSO
n=20	10	10	10	10
n=40	10	10	9	10
n=60	7	6	5	6
n=80	3	10	5	10
n=100	1	6	3	7
Total	31	**42**	**32**	**43**
Class 2				
n=20	10	10	10	10
n=40	10	9	9	9
n=60	4	10	9	10
n=80	10	9	8	9
n=100	10	10	9	10
Total	44	**48**	**45**	**48**
Class 3				
n=20	9	10	10	10
n=40	9	6	5	6
n=60	5	5	1	6
n=80	0	4	1	4
n=100	0	5	1	5
Total	23	**30**	**18**	**31**

Class 4	BB	MOEA	MOPSO	HMOPSO
n=20	10	10	10	10
n=40	10	10	10	10
n=60	7	8	8	8
n=80	10	7	7	7
n=100	10	8	7	8
Total	47	43	42	43
Class 5				
n=20	10	9	10	9
n=40	10	8	9	10
n=60	8	5	5	6
n=80	0	3	3	3
n=100	1	3	0	2
Total	29	28	27	30
Class 6				
n=20	10	10	10	10
n=40	5	6	6	9
n=60	10	9	9	6
n=80	10	10	10	10
n=100	2	8	7	8
Total	37	**43**	**42**	**43**

Number of optimal solution obtained

PSO for the BPP: Simulation Results

- Computational Efficiency
  - stop after 1000 iterations or no improvement in last 5 generations
  - MOPSO obtained inferior results compared to the other two

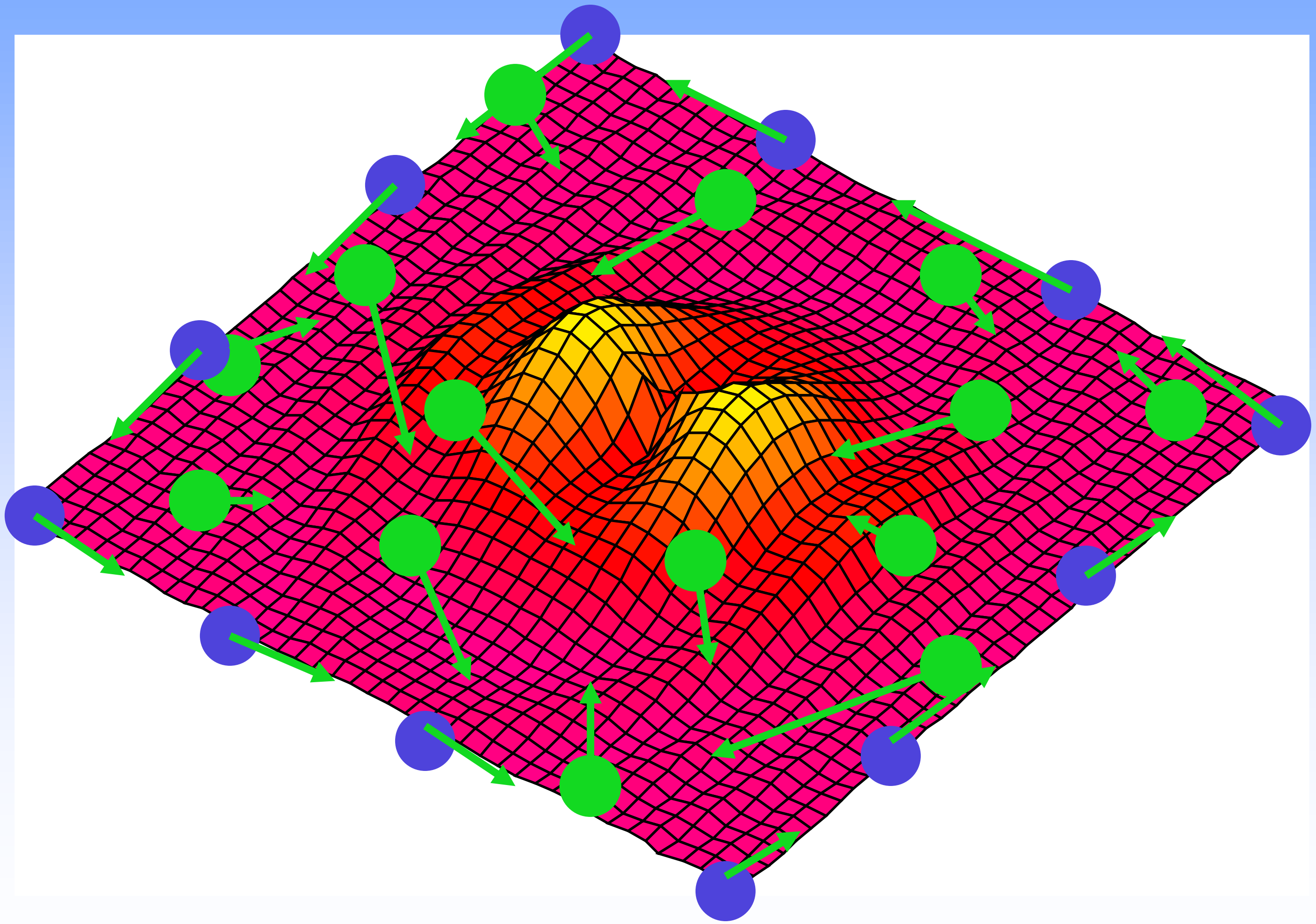


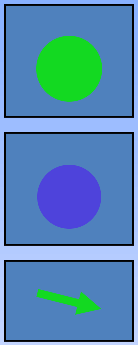
PSO for the BPP: Conclusions

- Presentation of a mathematical model for MOBPP-2D
- MOBPP-2D solved by the proposed HMOPSO
- BLF chosen as the decoding heuristic
- HMOPSO is a robust search optimization algorithm
  - Creation of variable length data structure
  - Specialized mutation operator
- HMOPSO performs consistently well with the best average performance on the performance metric
- Outperforms MOPSO and MOEA in most of the test cases used in this paper

The Particle Swarm Optimization Algorithm

Initialization. Positions and velocities

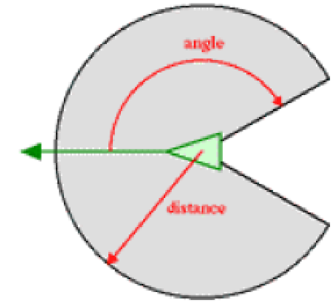




What a particle does

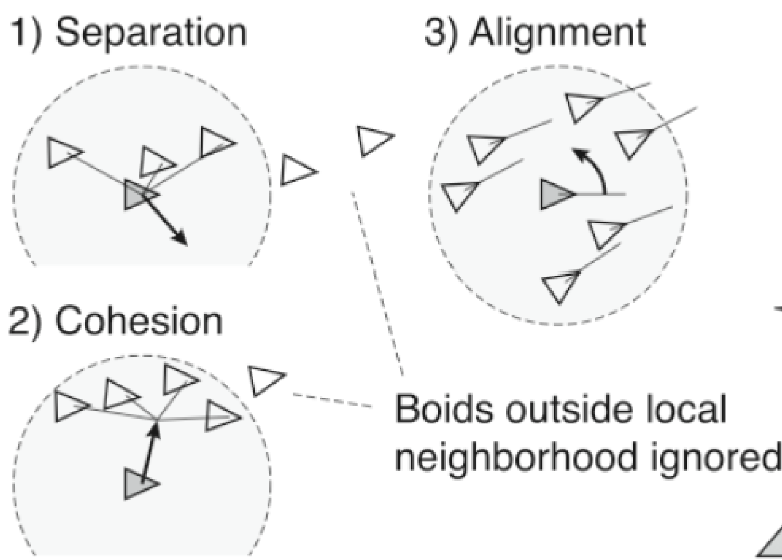
- In each timestep, a particle has to move to a new position. It does this by adjusting its *velocity*.
  - *The adjustment is essentially this:*
  - *The current velocity PLUS*
  - *A weighted random portion in the direction of its personal best PLUS*
  - *A weighted random portion in the direction of the neighbourhood best.*
- *Having worked out a new velocity, its position is simply its old position plus the new velocity.*

Reynolds Flocking (1987)

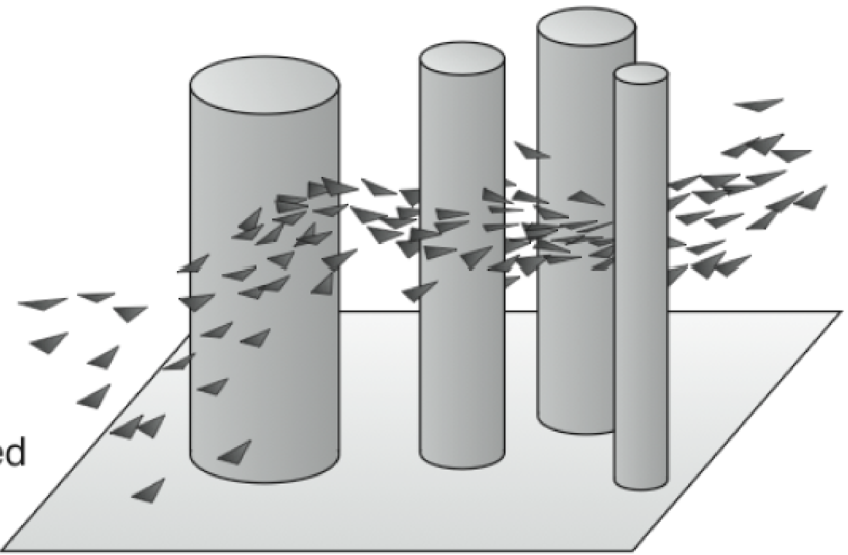


Sensing: Boid perceives angle and distance of neighboring boids

Local rules



Emergent flocking behavior



1. **Separation:** Boid maintains a given distance from other boids
2. **Cohesion:** Boid moves towards center of mass of neighboring boids
3. **Alignment:** Boid aligns its angle along those of neighboring boids

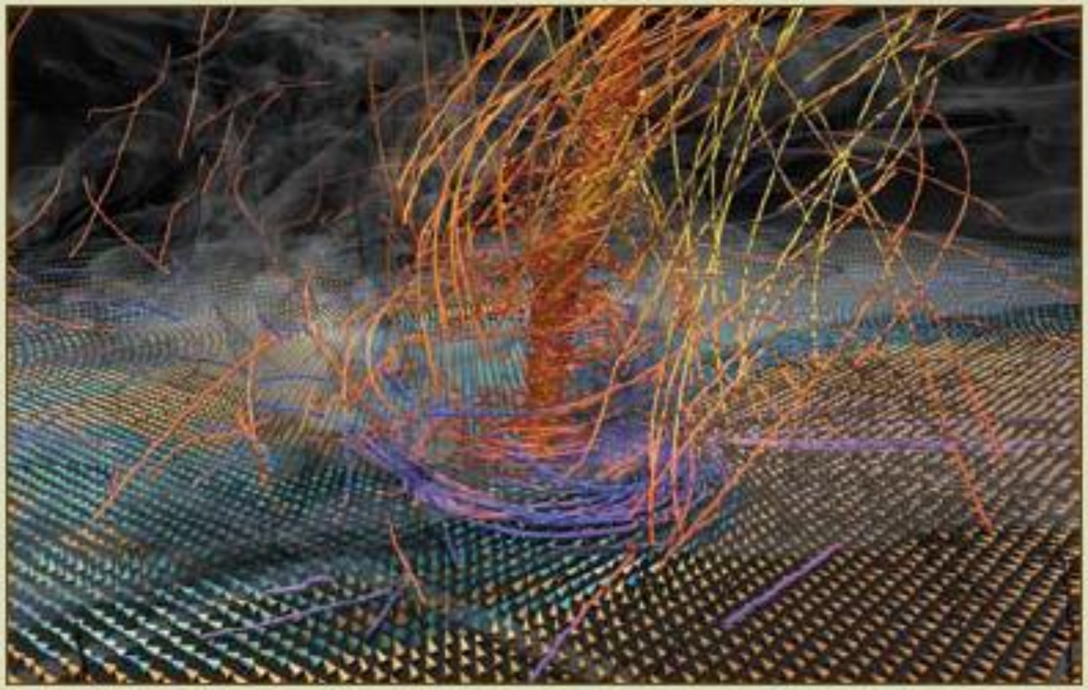
Coordinated navigation of swarms

Complexity and Emergence

Nature abounds with examples of complex systems that show emergent phenomena, patterns of structure or behavior seen at one scale of a system that arise from interactions among system components at other scales of length, time, or number of components. Examples include the beating of a heart, the biological origin of a thought, the evolution of weather patterns, and the dynamics of some economic phenomena.

- Complex systems are ubiquitous and to understand them requires contributions from multiple disciplines. Recent mathematical achievements have advanced the study of complex problems in geospace. These problems couple phenomena occurring at atomic scales with those occurring at astronomical scales, for example through the study of electromagnetic processes that control plasmas.
- The cross-fertilization of ideas and methods from biology and chemistry with those from the physics of complex systems has led to new approaches to a variety of critical issues including the evolution and functioning of genetic regulatory networks, the specificity of protein-protein interactions, the dynamic control of cell motility, and the neural synaptic mechanisms underlying learning.
- Analogies from the life sciences are motivating the design of self-assembling and self-repairing materials.
- Communities of researchers—spanning engineering and geosciences to behavioral science—are working together to forecast, prepare for, and respond to natural and human-induced disasters.

NSF funding to improve understanding, modeling, and harnessing of complex systems will have far-reaching consequences across the entire spectrum of science and engineering.



Computer visualization techniques improve comprehension of complex phenomena such as the formation of tornadoes.

ComPlexUs 2003

The Physical Modelling of Human Social Systems

Philip Ball

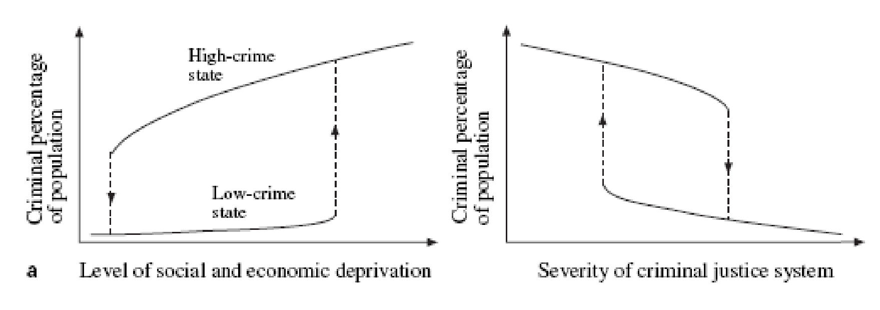
Nature, London, UK

For editorial comment see p. 207

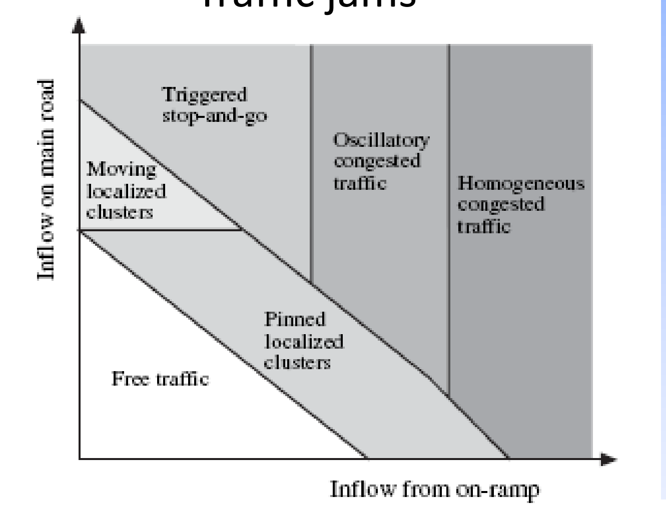
Key Words
Sociology · Phase transitions · Statistical physics · History of science · Collective behaviour

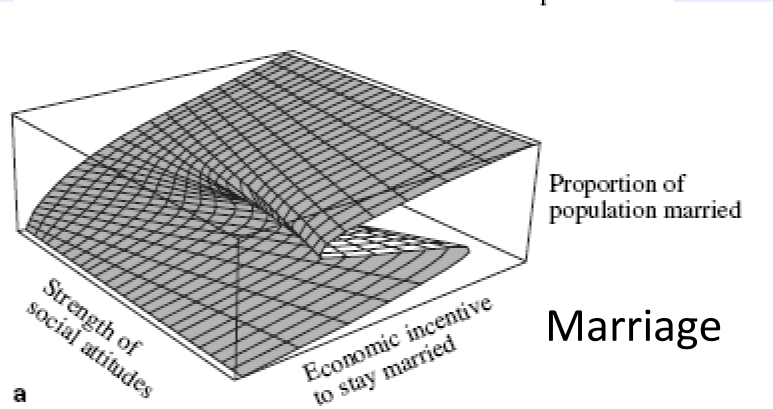
Abstract
One of the core assumptions in the study of complex systems is that there exist 'universal' features analogous to those that characterize the notion of universality in statistical physics. That is to say, sometimes the details do not matter: certain aspects of complex behaviour transcend the particularities of a given system, and are to be anticipated in any system of a multitude of simultaneously interacting components. There can be no tougher test of this idea than that posed by the nature of human social systems. Can there really be any similarities between, say, a collection of inanimate particles in a fluid interacting via simple, mathematically defined forces of attraction and repulsion, and communities of people each of whom is governed by an unfathomable wealth of psychological complexity? The traditional approach to the social sciences has tended to view these psychological factors as irreducible components of human social interactions. But attempts to model society using the methods and tools of statistical physics have now provided ample reason to suppose that, in many situations, the behaviour of large groups of people can be understood on the

Spread of Crime



Traffic jams





Marriage

Collective minds

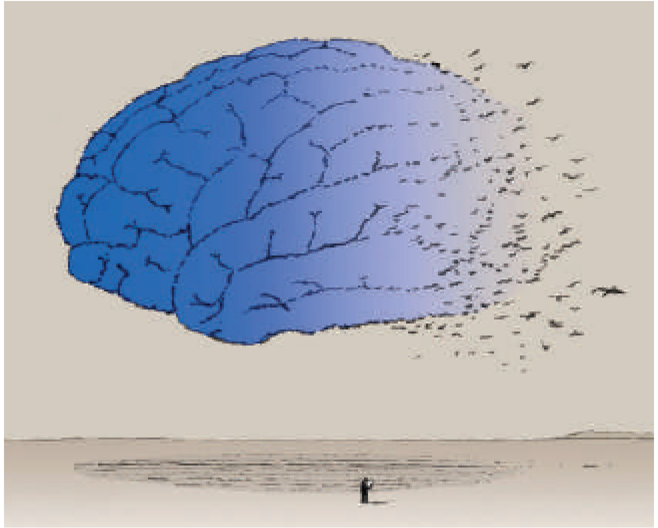
By tapping into social cues, individuals in a group may gain access to higher-order computational capacities that mirror the group's responses to its environment.

Iain Couzin

In 1905 the field naturalist Edmund Selous, a confirmed Darwinian and meticulous observer of bird behaviour, wrote of his wonderment when observing tens of thousands of starlings coming together to roost: "they circle; now dense like a polished roof, now disseminated like the meshes of some vast all-heaven-sweeping net…wheeling, rending, darting…a madness in the sky".

Throughout his life Selous struggled to explain the remarkable synchrony and coherence of motion during flocking, and he concluded that somehow a connectivity of individual minds and transference of thoughts must underlie such behaviour. "They must think collectively, all at the same time, or at least in streaks or patches — a square yard or so of an idea, a flash out of so many brains".

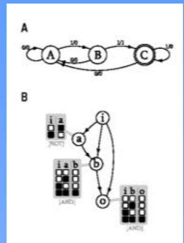
We now know that such synchronized group behaviour is mediated through sensory modalities such as detected by only a relatively small proportion of group members due to limitations in individual sensory capabilities, often further restricted by crowding. Close behavioural coupling among near neighbours, however, allows a localized change in direction to be amplified, creating a rapidly growing and propagating wave of turning across the group. This positive feedback results from the ability of individuals

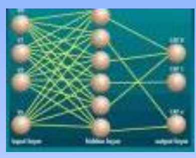


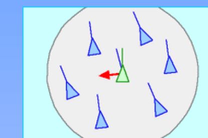
J. KAPUSTA/IMAGES.COM

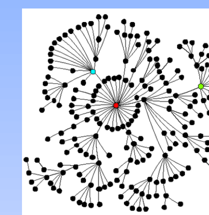
example, animals are often faced with the challenge of navigating up noisy and weak thermal or resource gradients. Local variability makes this task difficult, or even impossible, for individuals in isolation. But coherent social interactions can allow groups to function like an integrated self-organizing array of sensors, again increasing effective perceptual range. As long as interactions are sufficiently sensitive to ensure cohesion, but not too sensitive to local fluctuations and individual error, individuals can effectively respond to the weak long-range gradient.

We are beginning to comprehend more fully how individuals in groups can gain access to higher-order collective computational capabilities such as the simultaneous acquisition and processing of information from widely distributed sources. Group members may come to a consensus not only about where to travel but also about what local rules to use. Thus, like the brain, groups may adapt to compute 'the right thing' in









Complex Systems Theory and Methods

Agent-based modeling (including cell automata)
Chaos, Fractals, & Dynamical systems theory
Complex Network science
Game Theory
Multi-scale modeling
Distributed control
Nonlinear pattern recognition and data mining
Evolutionary, Adaptive, Developmental approaches
Bio-inspired Computing (ANNs, EC)
Etc.

Complex Systems Science is at an exciting time of Maturation

Data Collection Technology

High-throughput Microarrays
Molecular Imaging
Distributed Sensor Networks
Web mining, Etc.

Increasing Recognition of the Limits of Reductionism

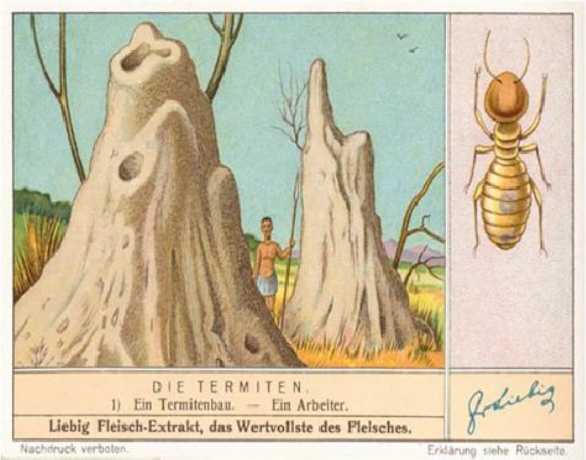
Computational Capabilities

Massive Data Storage
Rapid Data Access
Processor speed
Distributed and parallel computing
Etc.

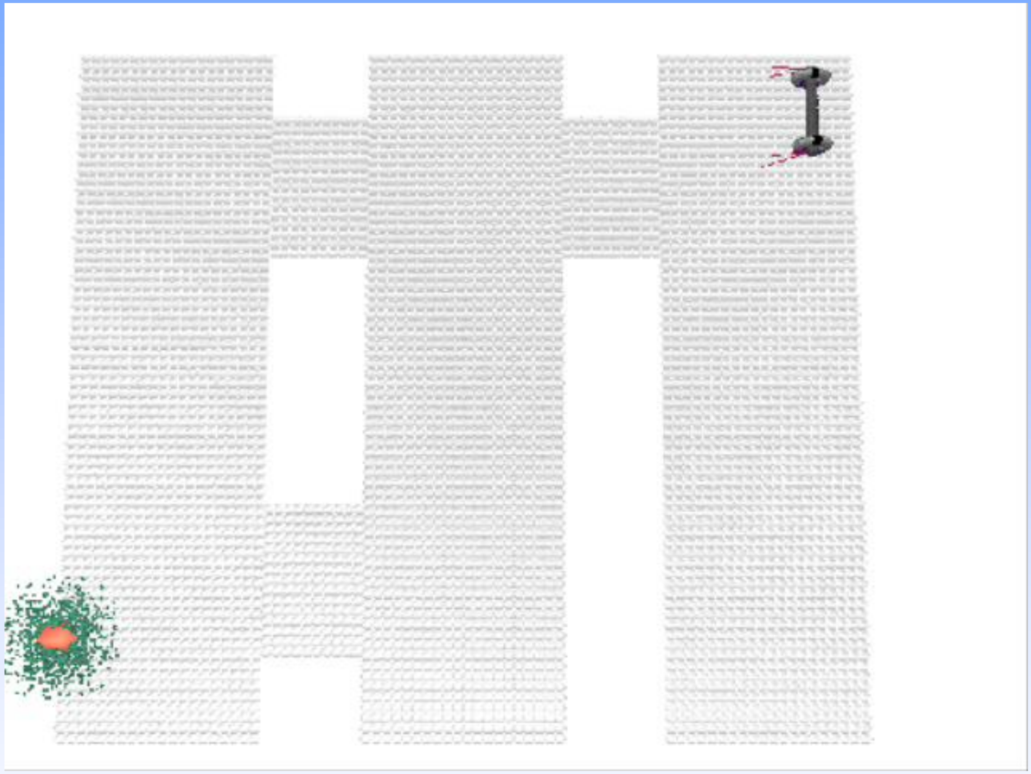
Emergenssi

Social Insects (2)

- Create remarkable structures



Liebig card, 1937, Card set number 1107

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