ROBOTMEET2022, August 18-20, 2022, Edinburgh, Scotland, UK
(key advances in Robot Intelligence Technology and Applications)

Viniculture based on the Lattice Computing Paradigm

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Outline

1. Brief viewpoints (2 slides)
2. World Representations and Data Representations (7 slides)
3. The Lattice Computing (LC) Paradigm for Intelligence Modelling (7 slides)
4. Agricultural applications (5 slides and 1 video ~2.5 min)
5. Conclusion (1 slide)

1. A brief viewpoint of technology

- **Industry 1.0** or, equivalently, the (classic) industrial revolution, has been called the transition from manual production to mechanical (steam) production from the late 18th century to the early 19th century.
- The second industrial revolution (**Industry 2.0**), from the late 19th century to the early 20th century, was shaped by the widespread use of electricity.
- The third industrial revolution (**Industry 3.0**), in the second half of the 20th century, was shaped by the widespread use of digital computers.
- Currently, the fourth industrial revolution (**Industry 4.0**) is driven by advanced artificial intelligence as well as by the Internet.
- An industrial trend toward a cooperative integration of humans with robots/machines has been named **Industry 5.0** [3].

1. A brief viewpoint of human history (*cont.*)

- Any wealth of a nation seems, among other, to be an increasing function of the number of workers a nation engages.
- The number of workers can be increased in various manners. A promising manner is using robots.
- A collaborative team of workers seems to be far more productive than a non-collaborative team.
- Historically, an effective collaboration of humans was first made possible thanks to *logic*, or *λόγος* (*logos*) in Greek.
- Our intention is to develop collaborative teams of robot workers based on logic.

2. World representation (*cont.*)

Robots are driven by computers, by implementing (mathematical) models in software.

A model is developed in a world representation. The latter is, typically, the Euclidean space R^N, where R emerges from the conventional measurement process of successive comparisons.

Modeling in R^N has been quite successful in physical world applications. However, when humans are involved then data other than numbers may appear such as "propositions".

In the aforementioned context, there is a need to extend the Euclidean space R^N to another space.

2. World representation

Our proposal is to extend R to a mathematical lattice L (including lattice R, as a special case).

Then, extend the Euclidean space R^N to the Cartesian product $L_1 \times \ldots \times L_N$ of N (probably disparate) mathematical lattices $L_1, \ldots, L_N$.

Lattices are amenable to rigorously defined functions of logic.

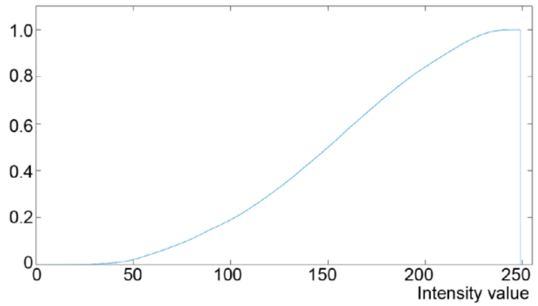
2. Data representations

2.1 Intervals' Numbers (INs) (*cont.*)

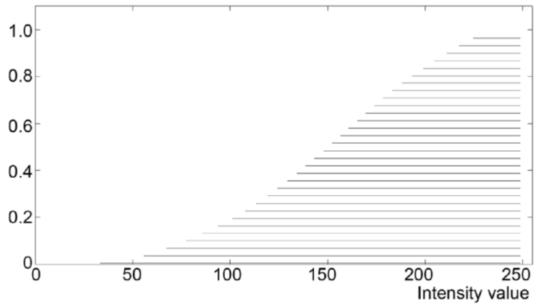
Two equivalent representations of an Intervals' Number (IN).

(a) The **membership-function-representation** of an IN is amenable to interpretations; e.g. it may represent a distribution function.

(b) The **interval-representation** of an IN is amenable to useful algebraic operations.



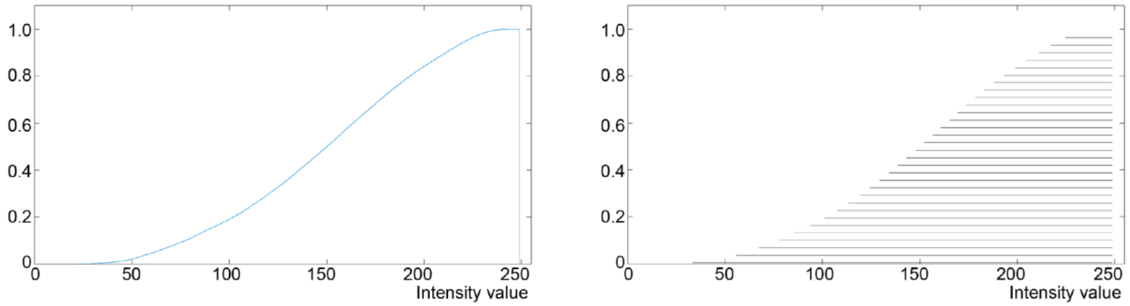
(a)



(b)

The main advantage of an IN:

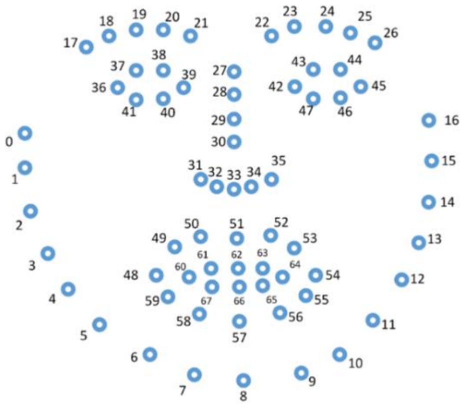
All-order data statistics can be represented, using a “small” number of L intervals. Therefore, no *ad hoc* feature extraction is required, but only an optimal estimation of the underlying positive valuation function.



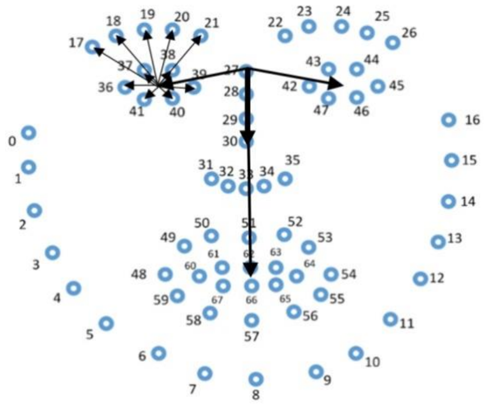
(a) (b)

The space F of INs includes the set of real numbers, i.e. $R \subset F$.

2.2 Tree Data Structures (*cont.*)



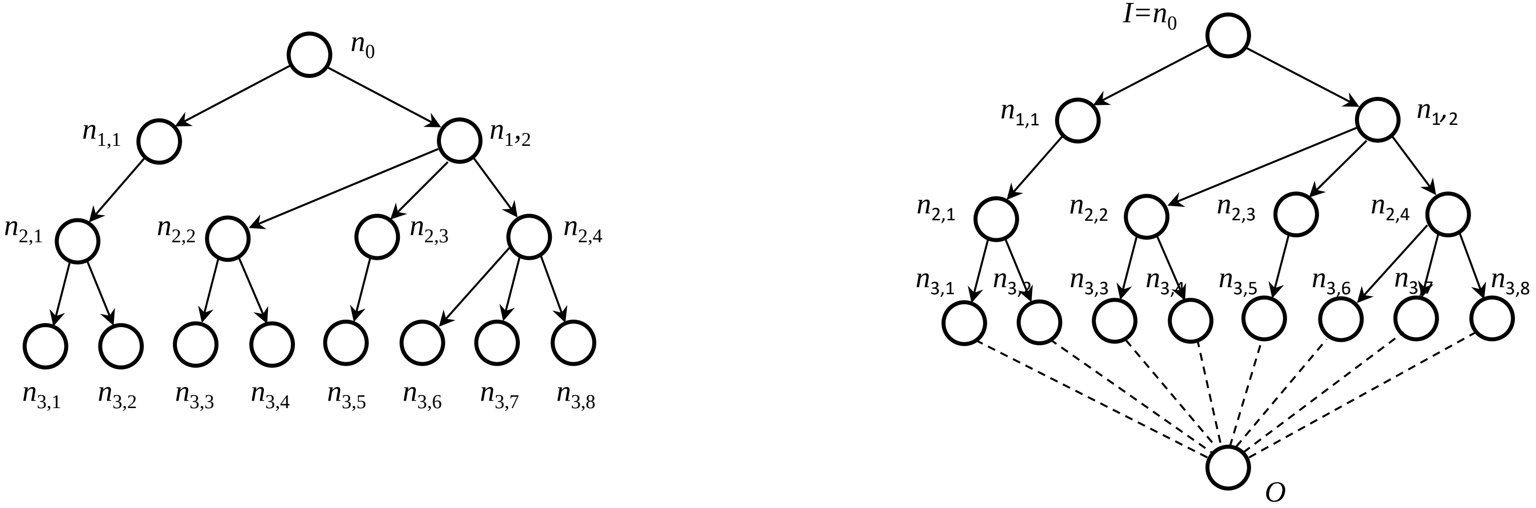
(a)



(b)

(a) 68 facial landmark points on a human face. (b) The *unit vector* defined along the nose. The first three *primary vectors* are also shown to the centers of the eyes and mouth as well as *secondary vectors* from the left eye center.

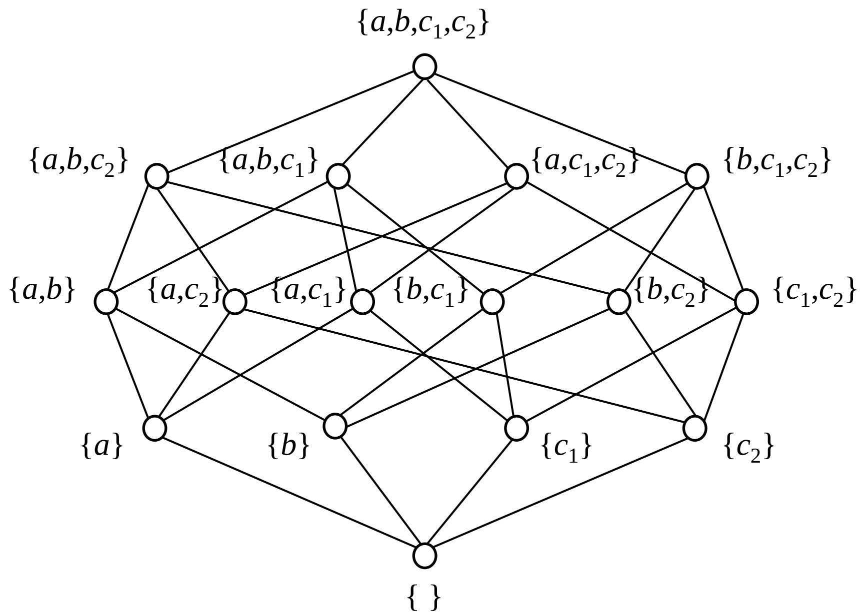
2.2 Tree Data Structures



(a) (b)

(a) A tree data structure example. (b) A lattice results in by inserting an additional level including the least lattice element *O*. The tree root corresponds to the greatest lattice element $I=n_0$.

2.3 Ontologies



A Boolean lattice ontology of the four inequality constraints *a*: $TSS_{min} < TSS < TSS_{MAX}$, *b*: $TA_{min} < TA < TA_{MAX}$, c_1: $pH < pH_{MAX}$ and c_2: $pH_{min} < pH$, regarding grape maturity indices TSS, TA and pH.

3. Lattice Computing (LC) paradigm for Intelligence Modelling

Instruments from Mathematical *Lattice Theory* or *Order Theory*.

Given a lattice $(\mathsf{L},\sqsubseteq)$, a *valuation* is a real function $v\colon \mathrm{L} \to \mathrm{R}$ given by $v(x \sqcap y) + v(x \sqcup y) = v(x) + v(y)$, $x,y \in \mathsf{L}$. A valuation is called *monotone* if $x \sqsubseteq y \Rightarrow v(x) \leq v(y)$, and *positive* if $x \sqsubset y < v(x) < v(y)$.

Let $(\mathsf{L},\sqsubseteq)$ be a lattice. An *inclusion measure* function $\sigma\colon \mathsf{L}\times\mathsf{L}\to[0,1]$ is defined by the two conditions:

$$
\begin{aligned}
&1. \quad u \sqsubseteq w \Leftrightarrow \sigma(u,w) = 1 \\
&2. \quad u \sqsubseteq w \Leftrightarrow \sigma(x,u) \leq \sigma(x,w)
\end{aligned}
\qquad (1)
$$

An inclusion measure $\sigma\colon \mathsf{L}\times\mathsf{L}\to[0,1]$ can be interpreted as a *fuzzy order relation*; therefore, the notations $\sigma(u,w)$ and $\sigma(u \sqsubseteq w)$ are used interchangeably. Any use of an inclusion measure $\sigma(.,.)$ is called *Fuzzy Lattice Reasoning*, or *FLR* for short.

There are at least two different functions for defining an inclusion measure σ: $L\times L\rightarrow[0,1]$, both are based on a positive valuation function $v\!: \mathrm{L} \rightarrow \mathrm{R}$ in $(L,\sqsubseteq)$, as follows.

- $sigma-meet$: $\sigma_{\sqcap}(x,u) = v(x \sqcap u)/v(x)$
- $sigma-join$: $\sigma_{\sqcup}(x,u) = v(u)/v(x \sqcup u)$

A positive valuation $v\!: \mathrm{L} \rightarrow \mathrm{R}$ in $(L,\sqsubseteq)$ also defines a metric distance $d\!: \mathrm{L} \times \mathrm{L} \rightarrow \mathrm{R}_0^+$ given by

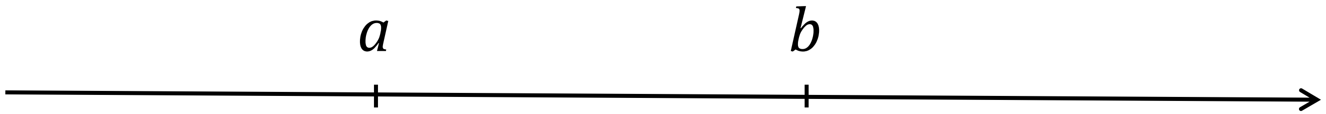
$$d(x,y) = v(x\sqcup y) - v(x\sqcap y).$$

A parametric valuation function $v(.)$ introduces tunable nonlinearities.

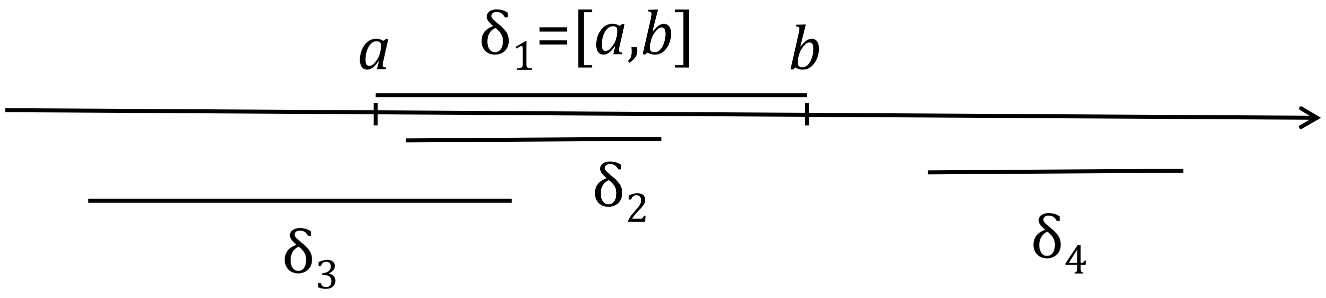
Intervals' Numbers (INs): Analysis in the context of *mathematical Lattice Theory*, or *Order Theory*.

A hierarchy of mathematical lattices stemming from R.

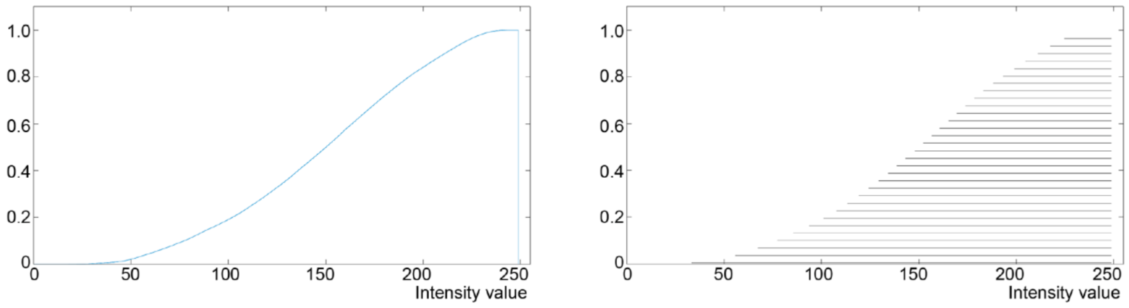
a) Level-0; the lattice (R;≤) of real numbers.



b) Level-1; the lattice (I_1;⊆) of intervals.



c) Level-2; the lattice $(F_1;\preccurlyeq)$ of Intervals' Numbers (INs).



(a) (b)

The lattice $(F_1;\preccurlyeq)$ is a *metric cone*; hence, ARMA models have been proposed.

Useful mathematical instruments in the lattice $(\mathsf{F}_1;\preccurlyeq)$ of INs:

- A ***metric*** distance function D_1: $\mathsf{F}_1\times\mathsf{F}_1 \to R_0^{\;+}$ defined as

$$D_1(F,G) = \int_0^1 d_1(F_h, G_h)dh, \text{ where}$$

d_1: $\mathsf{I}_1\times\mathsf{I}_1 \to R_0^{\;+}$ is a metric distance function defined as

$$d_1([a,b],[c,d])= v(\theta(a\wedge c))-v(\theta(a\vee c))+v(b\vee d)-v(b\wedge d),$$

where function v: $R\to[0,+\infty)$ is strictly increasing, whereas function θ: $R\to R$ is strictly decreasing.

- Two ***inclusion measure*** functions $\sigma_{\curlywedge}$: $F_1 \times F_1 \rightarrow [0,1]$ and $\sigma_{\curlyvee}$: $F_1 \times F_1 \rightarrow [0,1]$ defined as $\sigma_{\curlywedge}(F,G) = \int_0^1 \sigma_{\sqcap}(F_h, G_h)dh$ and $\sigma_{\curlyvee}(F,G) = \int_0^1 \sigma_{\sqcup}(F_h, G_h)dh$, where

$\sigma_{\sqcap}$: $I_1 \times I_1 \rightarrow [0,1]$ και $\sigma_{\sqcup}$: $I_1 \times I_1 \rightarrow [0,1]$ are *inclusion measure* functions defined as

$$\sigma_{\sqcap}(x=[a,b],y=[c,e]) = \begin{cases} 1, & x = \emptyset \\ \dfrac{v_1(x \sqcap y)}{v_1(x)} = \dfrac{v(\theta(a \vee c)) + v(b \wedge e)}{v(\theta(a)) + v(b)}, & x \supset \emptyset \end{cases}$$

$$\sigma_{\sqcup}(x=[a,b],y=[c,e]) = \begin{cases} 1, & x = \emptyset \\ \dfrac{v_1(y)}{v_1(x \sqcup y)} = \dfrac{v(\theta(c)) + v(e)}{v(\theta(a \wedge c)) + v(b \vee e)}, & x \supset \emptyset \end{cases}$$

where function v: $R \rightarrow [0,+\infty)$ is strictly increasing, function $\theta: R \rightarrow R$ is strictly decreasing.

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Advantages of LC models

1. They can deal with disparate types of data in Cyber-Physical System applications (including both numerical data for “physical” system component(s) and non-numerical data for “cyber” system component(s)).
2. They can compute with semantics (represented by a partial-order relation).
3. They can rigorously deal with ambiguity (by dealing with information granules).
4. They can naturally engage logic and reasoning.
5. They can process data fast.

4. Agricultural Applications (*cont.*)

Agricultural robots have an increasing popularity because they address vital issues such as seasonal shortages in manual labor.

The use of cooperative teams of agricultural robots in farming tasks is not as widespread. The interest here, in particular, is in skilful viniculture by a cooperative team of agricultural robots.

The technology for analysis and design is Lattice Computing (LC).

4. Agricultural Applications (*cont.*)

Data Acquisition

t=1

t=5

t=9

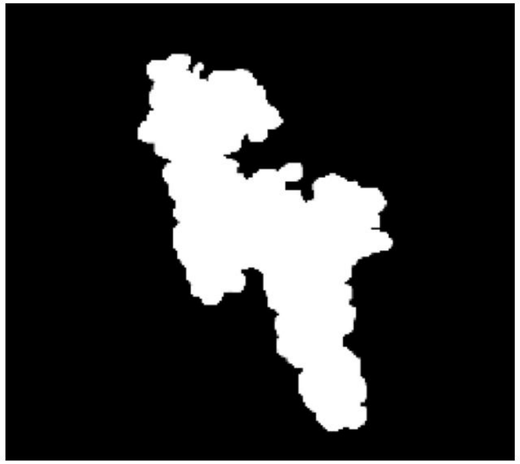
t=13

Pictures of grapes taken from a fixed distance, at the same time of the day at sampling times t=1 (August 10), t=5 (August 14), t=9 (August 20), and t=13 (August 25). The color of grapes progressively turns from green to black as grapes ripen.

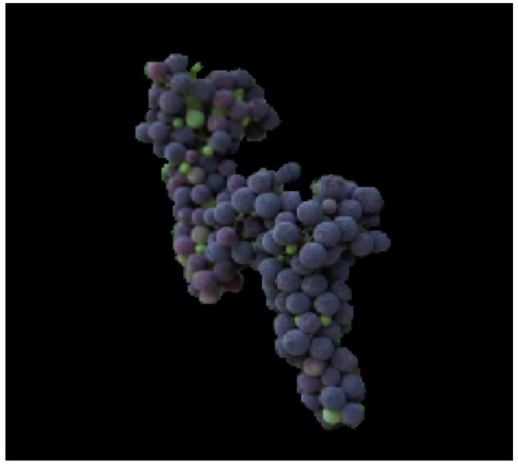
4. Agricultural Applications (*cont.*)

Preprocessing

(a)



(b)



(c)

(a) Original grape image. (b) A mask defined by a user, manually.
(c) The segmented image of interest includes only the grape in black background.

4. Agricultural Applications (*cont.*)

Histograms calculation

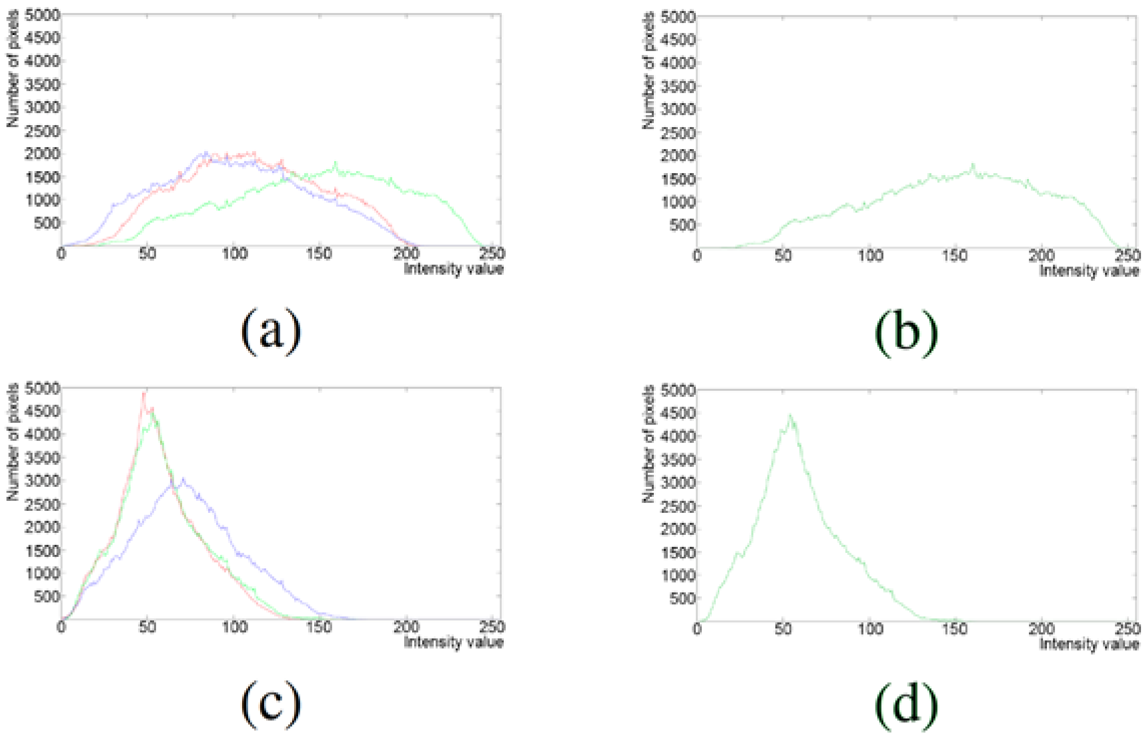
Histograms were calculated from digital images of grapes regarding the number of pixels per intensity level 0 - 255.

(a) RGB histograms calculated from an image taken on the first day.

(b) The G-channel histogram of the first day is displayed alone.

(c) RGB histograms calculated from an image taken on the last day -- Note that the histograms have moved to the left; moreover, they have become sharper.

(d) The G-channel histogram of the last day is displayed alone.



Intervals' Numbers (INs) induced from the Green Channel of RGB image histograms.

(a) ``Membership-function-representation'' of the IN on the first day.

(b) ``Interval-representation'' of the IN in (a).

(c) ``Membership-function-representation'' of the IN on the last day.

(d) ``Interval-representation'' of the IN in (c).

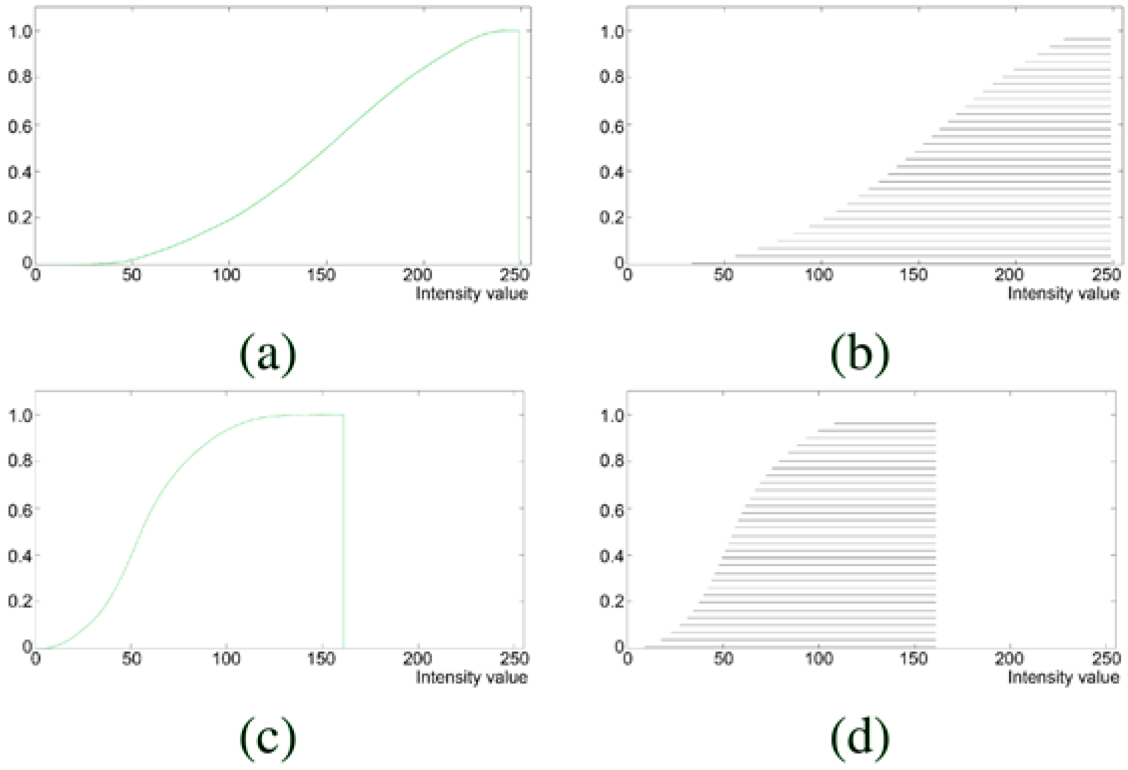


Fig. 1

Show video

(This video can be found at URL

http://humain-lab.cs.ihu.gr/index.php/2022/08/13/robot-intelligence-technology-for-skillful-viniculture-based-on-the-lattice-computing-paradigm/

in downloadable file

http://humain-lab.cs.ihu.gr/wp-content/uploads/2022/08/ROBOTMEET2022_KaburlasosVideo.mp4)

5. Conclusion

- Mathematical lattice-ordered data representations, including INs, tree data structures and ontologies, have been considered in agricultural applications.

- Logic-based LC models for decision-making as well as other LC models, e.g. IN regressors, all implementable in software, have been developed for *agrobots* (i.e. agricultural robots).

Acknowledgement

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http://humain-lab.cs.ihu.gr/index.php/projects/tegea/

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Selected References

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[2] E. Vrochidou, V. N. Tsakalidou, I. Kalathas, T. Gkrimpizis, T. Pachidis, V. G. Kaburlasos, "**An overview of end-effectors in agricultural robotic harvesting systems**", *Agriculture*, vol. 12, iss. 8, 1240, 2022. https://doi.org/10.3390/agriculture12081240

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Thank you

Questions ?

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(This presentation can be found at URL
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