

Eye-tracking analyses of pattern visualisation techniques for program comprehension

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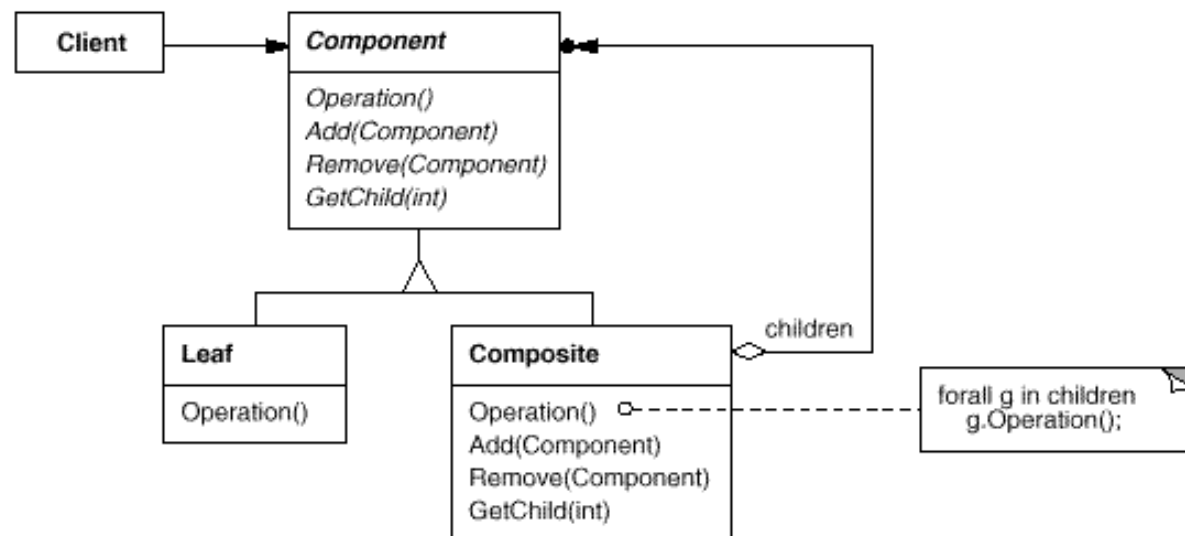


Context

- Design patterns [GJHV94]
 - Recurring design problems
 - Context
 - Consequences
 - **Design motif**
 - “Good” solution to the problem

Example

- Composite design pattern
 - Problem: composed objects in a whole–part relationship, transparent to clients
 - Design motif



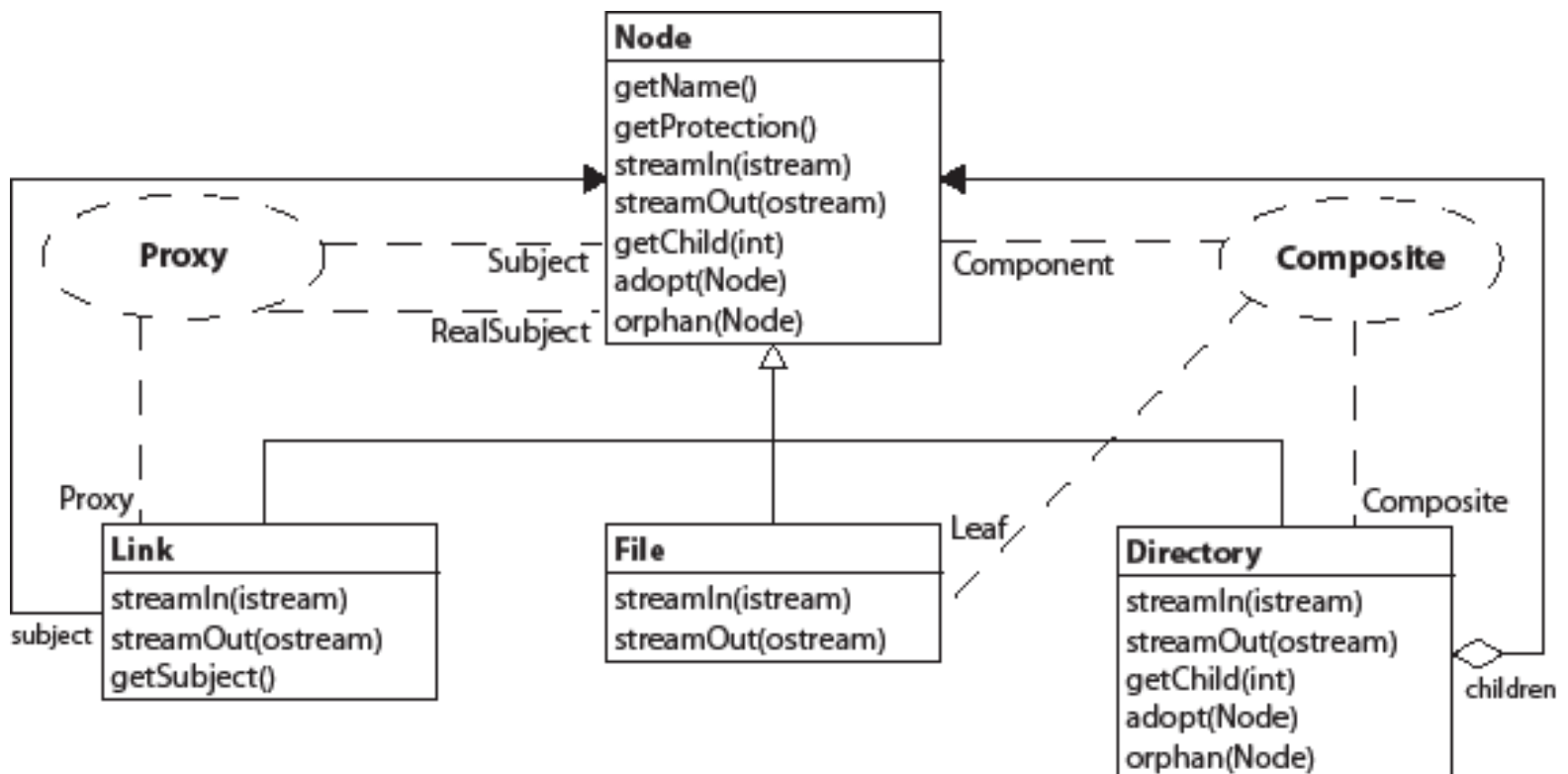


Context (cont'd...)

- Several works have for premises that
 - UML class diagrams are often used during development
 - The visual display of design motif eases program development
 - The usual representation of design motifs as “collaboration diagrams” is insufficient

Context (...end)

- Collaboration diagrams





State of the Art

■ Several works on

- Design patterns/motifs

- For example [ST02, ACC+07]

- Program comprehension

- For example [KKB+98, **Mal08**]

- Alternative representations

- Non-UML: [EYG97, MHG02]

- UML

- Mono-diagram: [GJHV94, Vli98, SK98, DYZ07, TT07]

- Multi-diagrams: [LK98, FKGS04]

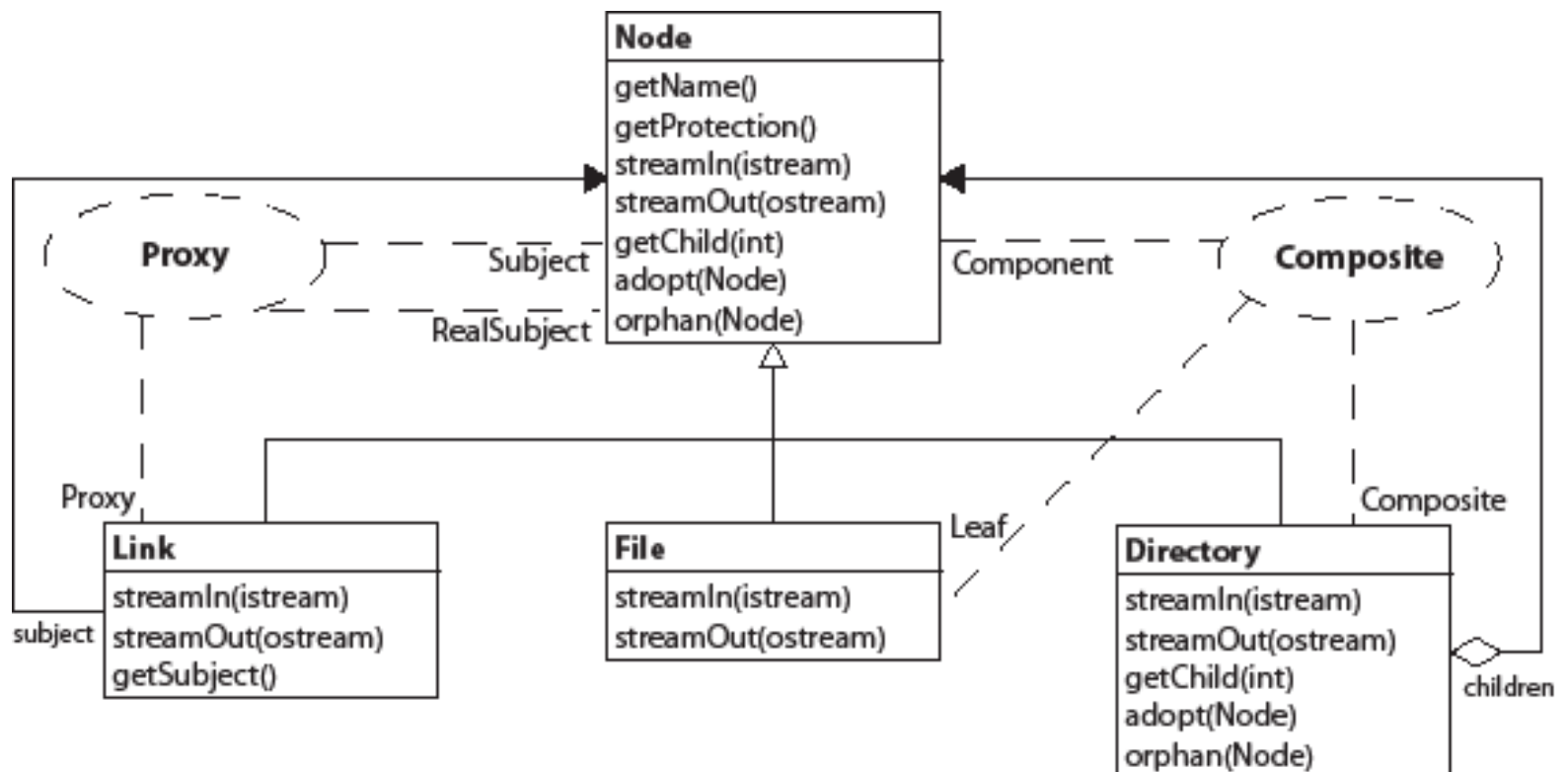


Research Questions

- To compare developers' performances when using the representations by
 - Dong [DYZ07]
 - Gamma [Vli98]
 - Schauer [SK98]
- with respect to UML collaboration diagrams during comprehension tasks

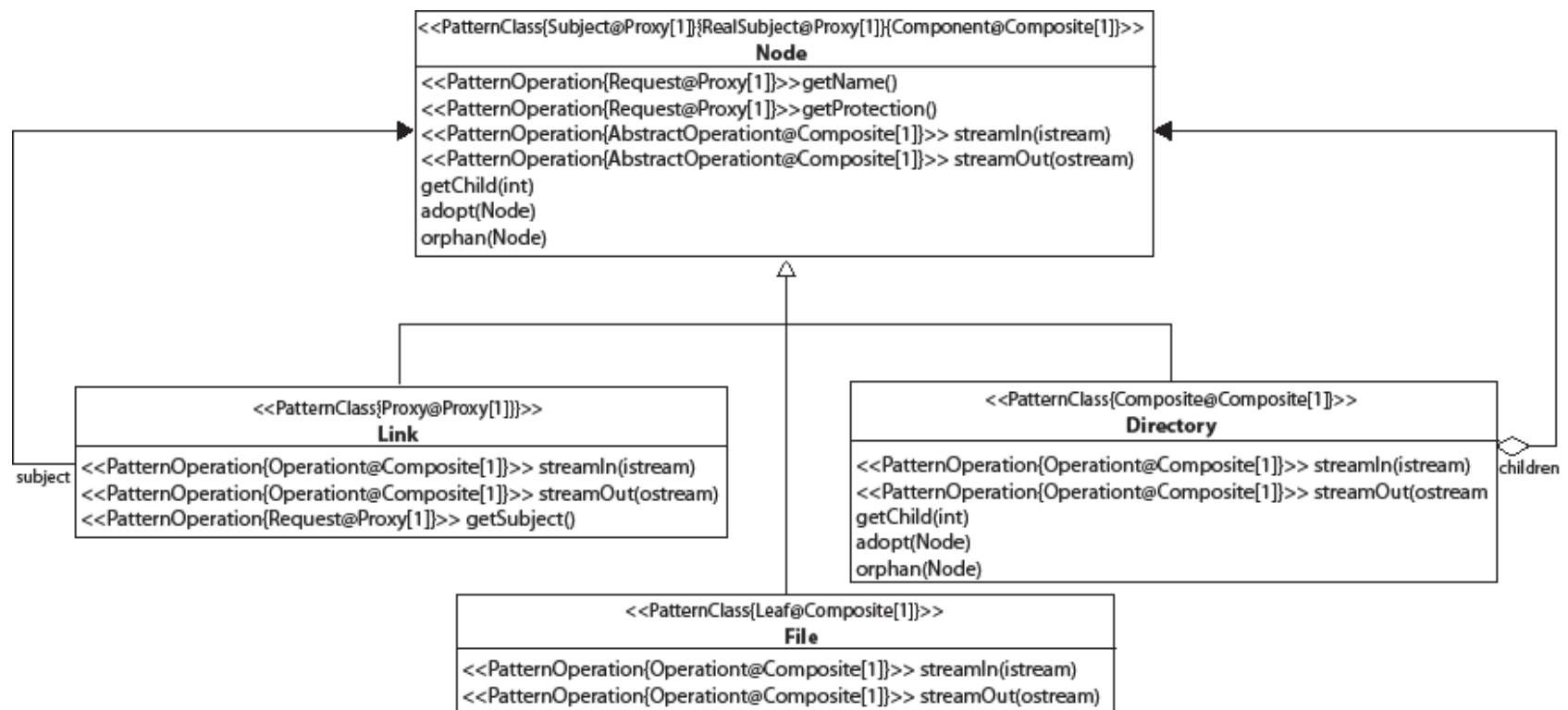
Representations

■ Collaboration diagrams



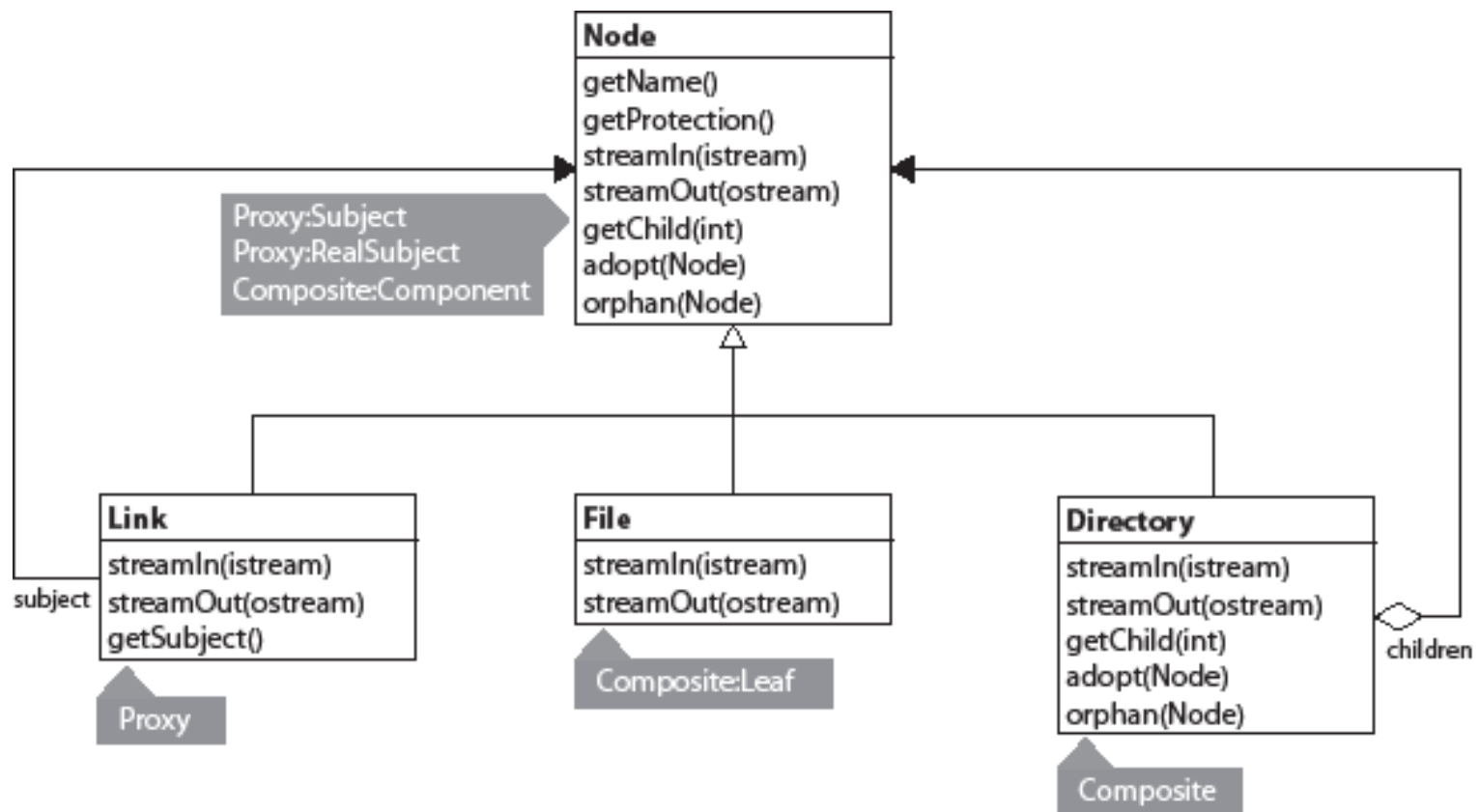
Representations

■ Dong [DYZ07]



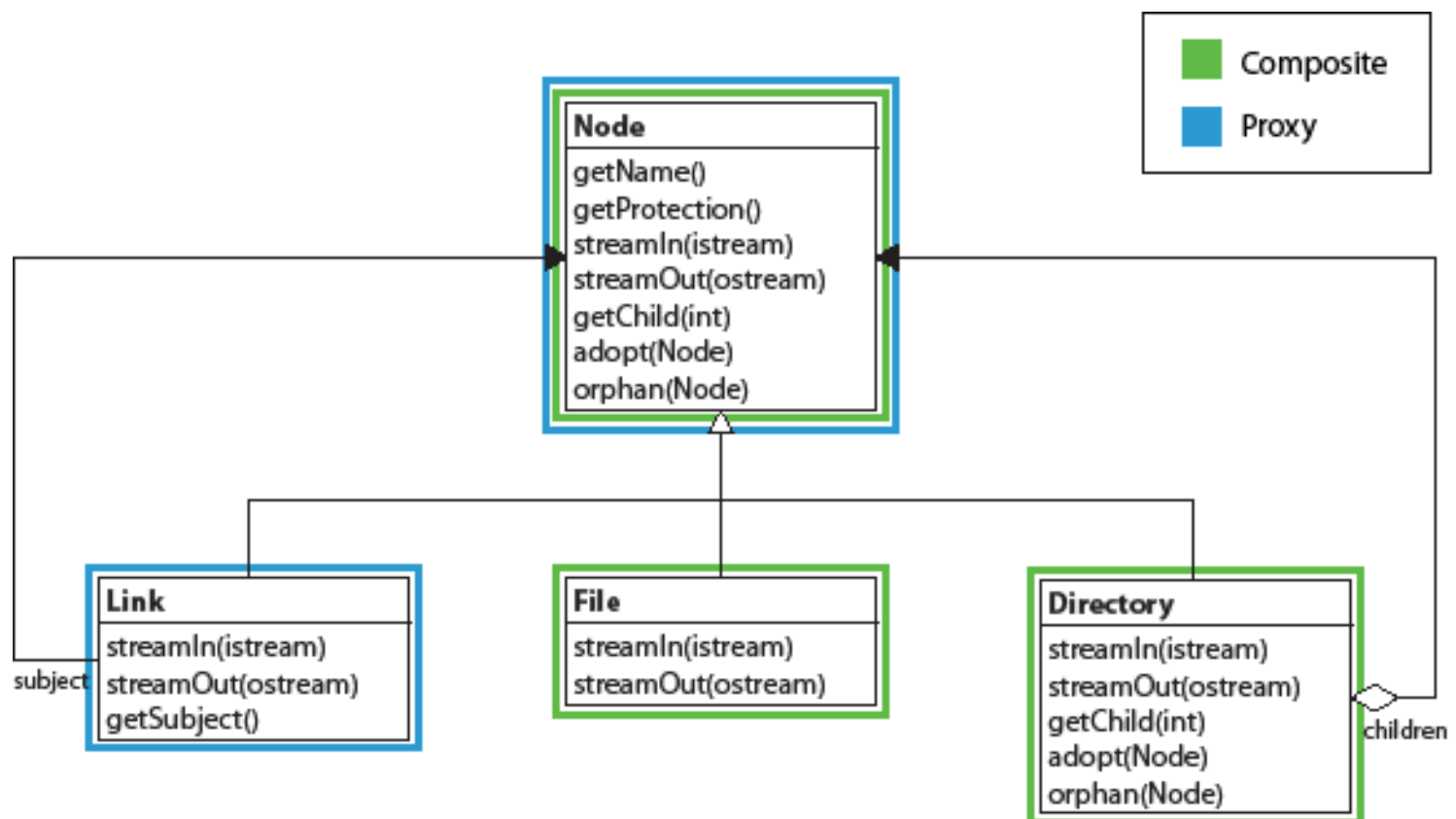
Representations

■ Gamma [Vli98]



Representations

■ Schauer [SK98]





Tooling

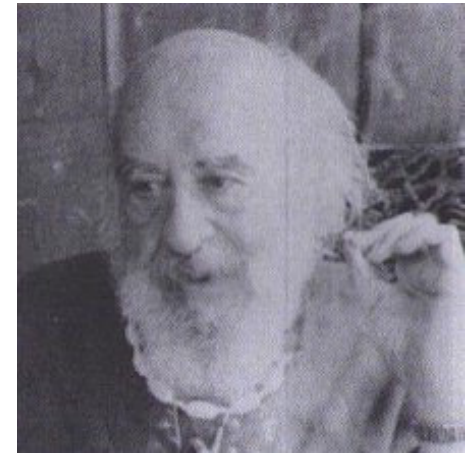
■ Eye-trackers

- Gather and analyse eye gaze data
- Based on the **Gestalt** and **cognitive** theories

Gestalt Theory

■ *Gestalten*

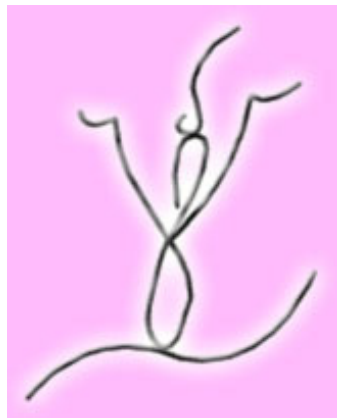
- To put into form,
to give a structure



Fritz Perls

*Berlin, July 8, 1893

†Chicago, March 14, 1970



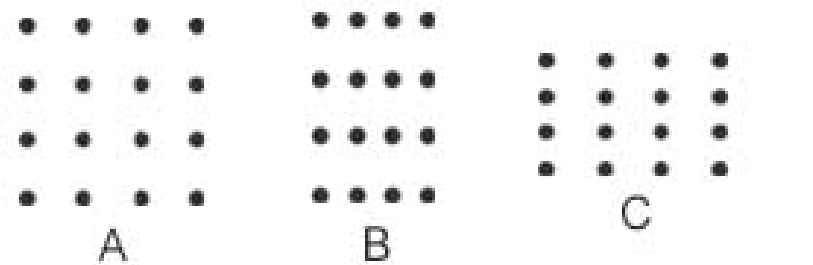
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Gestalt Theory

■ Laws of the Gestalt

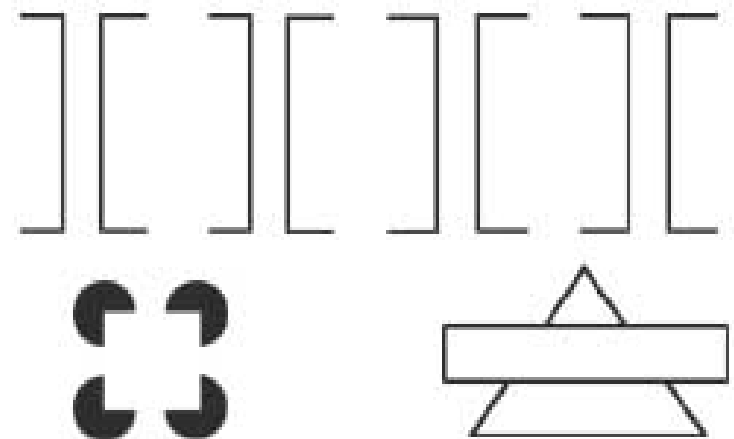
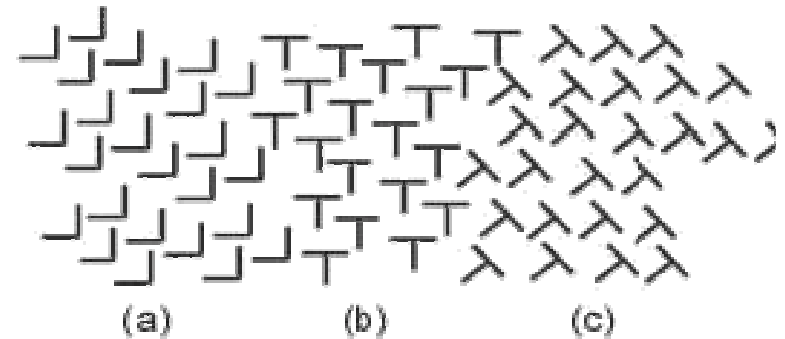
- Good form: simple, symmetrical, stable form
- Continuity: close points make forms
- Proximity: close points make groups
- Similitude: similar types of points make groups



Gestalt Theory

■ Laws of the Gestalt

- Common destiny: points having the same movements make forms
- Closure: closed form identified before opened form
- Completion: hidden parts are completed into a forms



Cognitive Theory

■ Principle

- Eye movements reveal cognitive processes, centers of interests (conscious and unconscious)



1



2



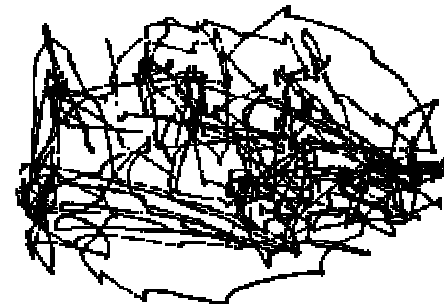
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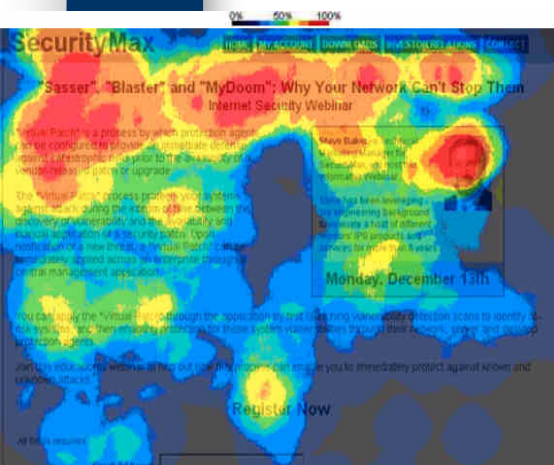
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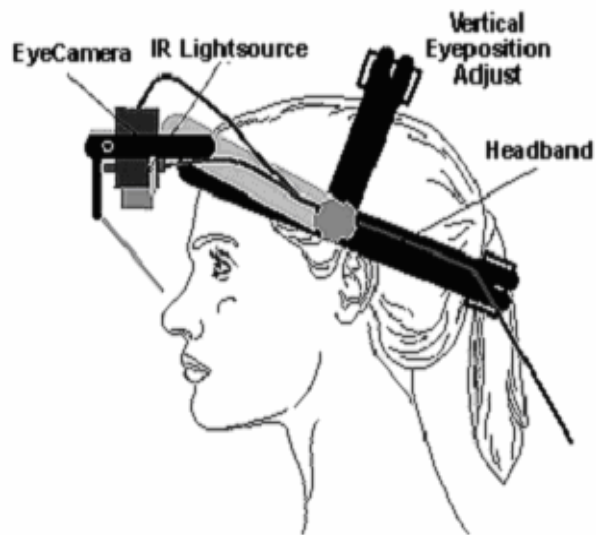


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Eye-trackers

- EyeLink II de SR Research
 - System





Eye-trackers

■ EyeLink II de SR Research

– Data

- **Fixations**
- **Saccades**
- **Scan path**

– Analyses

- Centres of interests
- Effort
- Duration
- ...



Experiments

■ Null hypotheses

- H_{0_1} : there is no difference between the subjects' average cognitive efforts when using UML collaboration diagrams and Schauer's representation.
- H_{0_2} : there is no difference between the subjects' average cognitive efforts when using UML collaboration diagrams and Gamma's representation.
- H_{0_3} : there is no difference between the subjects' average cognitive efforts when using UML collaboration diagrams and Dong's representation.

Experiments

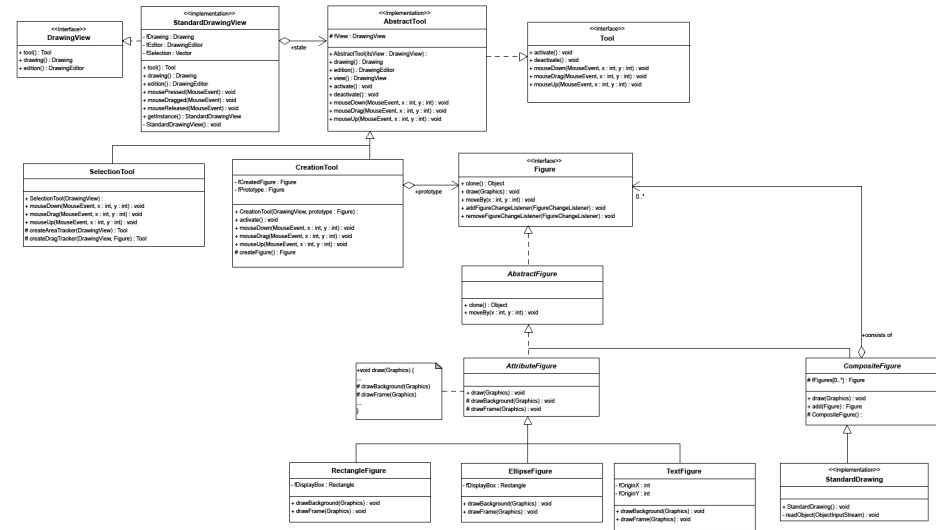
■ Alternative hypotheses

- $H_{\alpha_1.1}$: the subject's average cognitive efforts with Schauer's representation is greater than the ones with UML collaboration diagrams.
- $H_{\alpha_1.2}$: the subject's average cognitive efforts with Schauer's representation is less than the ones UML collaboration diagrams.
- ...

Experiments

■ Objects

- JHotDraw
- Class diagrams reverse-engineered using NetBeans
- Diagrams of 15 and 40 classes
- Composite, Prototype, Template Method, State and Singleton design motifs





Experiments

- Independent variables
 - Representations: D, G, S et U
 - Tasks
 - P, classes participation in a motif
 - C, motif composition
 - R, class role in a motif



Experiments

- Mitigating variables
 - Subjects' knowledge of JHotDraw
 - Lickert scale [0, 1, 2]
 - Subjects' knowledge of design motifs
 - Lickert scale [0, 1, 2]



Experiments

- Dependant variables
 - Performance: percentage of correct answers (PCR)

Experiments

■ Dependant variables

– Area of interest (ZDI)

- Fixation ratio

$$RFOA = \frac{\sum_{i=1} \text{SUM OF FIXATIONS IN ZDI } F_i}{\sum_{j=1} \text{SUM OF FIXATIONS IN ZDR } F_j}$$

- Fixation time ratio

$$RTFOA = \frac{\sum_{i=1} \text{SUM OF FIXATIONS IN ZDI } (TF(F_i) - TI(F_i))}{\sum_{j=1} \text{SUM OF FIXATIONS IN ZDR } (TF(F_j) - TI(F_j))}$$

- Average fixation time

$$DMF = \frac{\sum_{i=1} \text{NUMBER OF FIXATIONS } (TF(F_i) - TI(F_i))}{\#\{Fixations\}}$$

Experiments

■ Subjects

- 24 volunteers
- 2nd or 3rd grads at University of Montreal
- Balanced groups
 - 3 tasks per subjects et number of classes
 - Minimisation of the learning effect

	15	40
D	$S_9, S_{11}, S_{12}, S_{21}, S_{23}, S_{24}$	$S_3, S_5, S_6, S_{13}, S_{17}, S_{18}$
G	$S_6, S_8, S_{10}, S_{18}, S_{20}, S_{22}$	$S_2, S_4, S_{12}, S_{14}, S_{16}, S_{24}$
S	$S_4, S_5, S_7, S_{16}, S_{17}, S_{19}$	$S_1, S_{10}, S_{11}, S_{13}, S_{22}, S_{23}$
U	$S_1, S_2, S_3, S_{13}, S_{14}, S_{15}$	$S_7, S_8, S_9, S_{19}, S_{20}, S_{21}$

Experiments

■ Questions and stimuli

Task of motif composition: C

Q1. Name all motifs in which class CreationTool participate.
--

Q2. Name all motifs in which class AttributeFigure participate.

Task of class participation: P

Q5. Name of classes participating in the Composite motif.

Q6. Name all classes participating in the State motif.
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Task of role identification: R

Q3. Name all roles played in some motifs by class AbstractFigure.

Q4. Name all roles played in some motifs by class StandardDrawingView.
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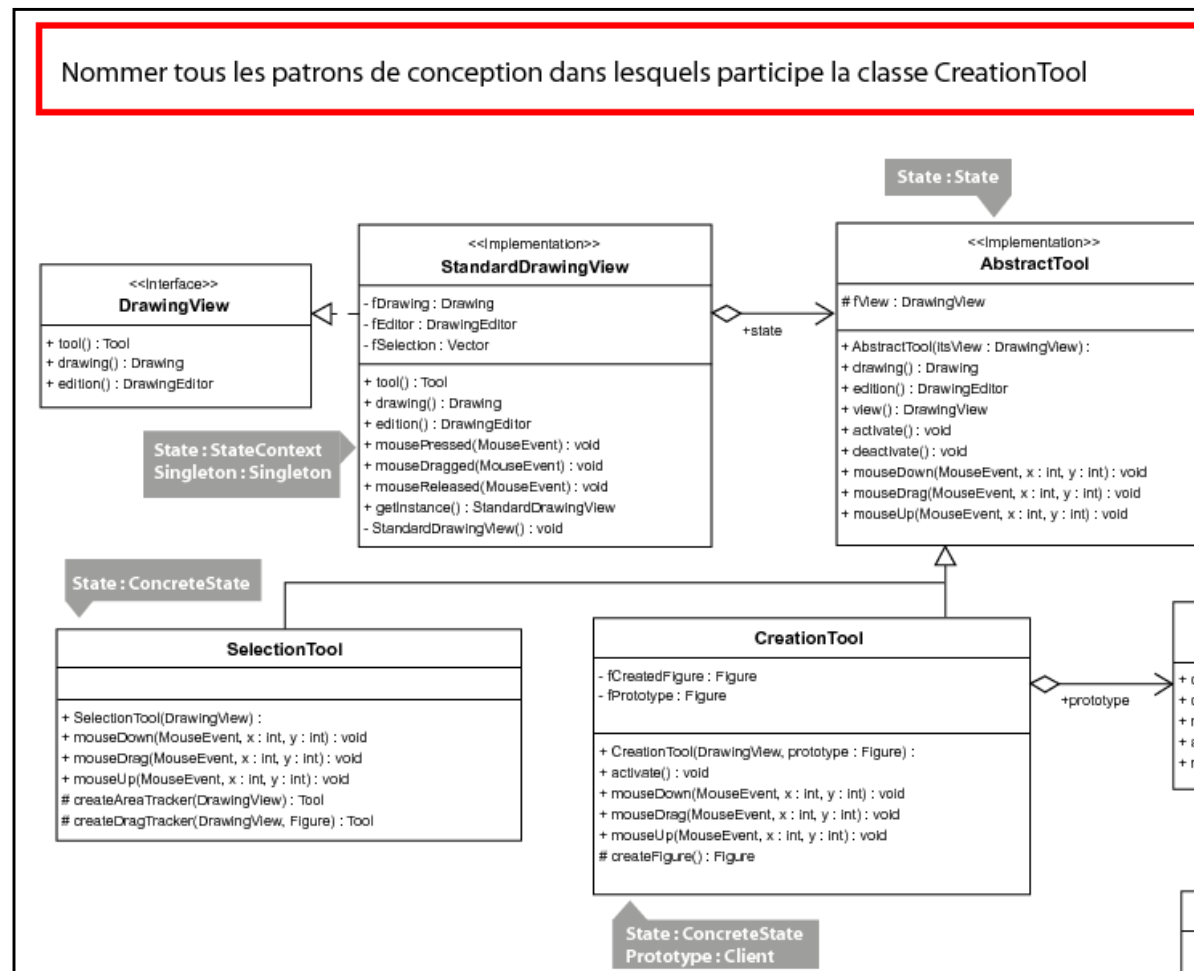


Analyses and results

- **Statistic analyse**
 - Student t-test
- **Removal of outlier values**
 - Values in the 3rd quartiles and beyond

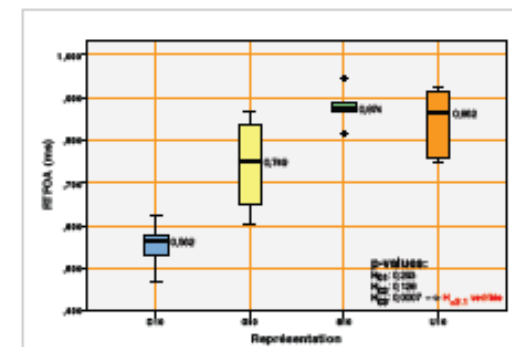
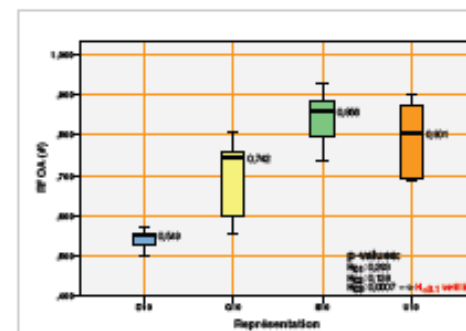
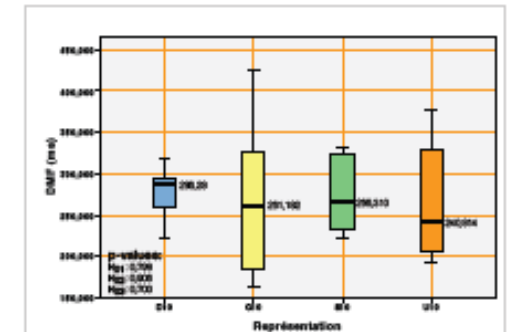
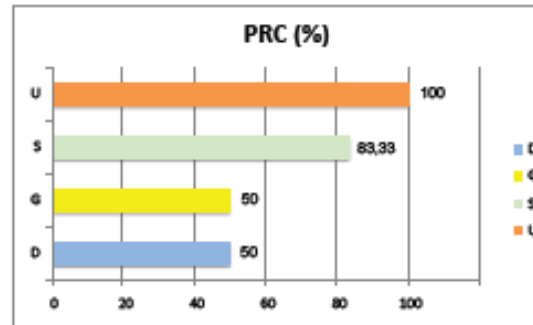
Analyses and results

■ Diagram with 15 classes, P



Analyses and results

- Diagram with 15 classes, **P**



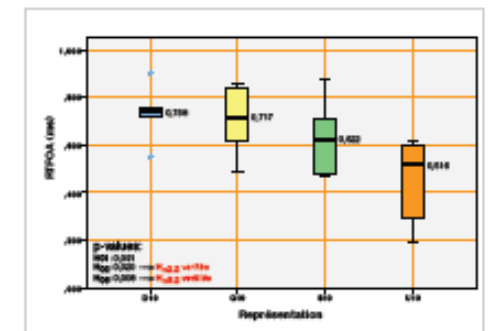
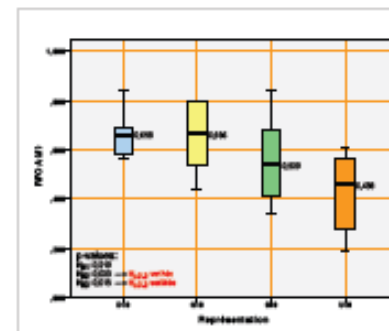
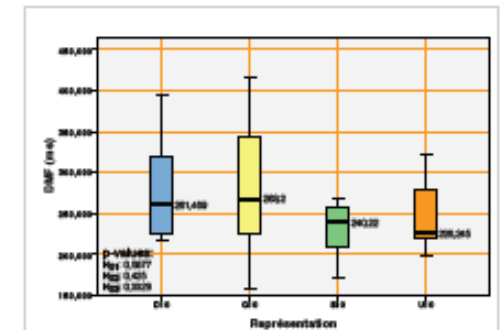
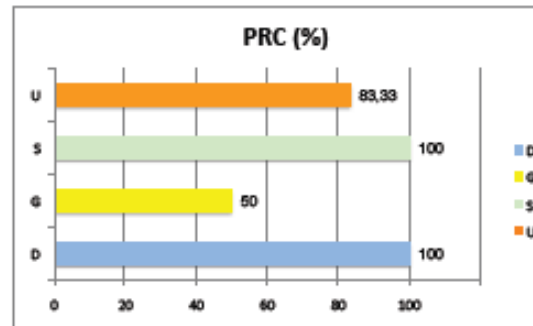
	P_D15	P_G15	P_S15	P_U15	p-value (H_{01})	p-value (H_{02})	p-value (H_{03})
PRC (%)	50	50	83,33	100	—	—	—
DMF (ms)	277,619	270,608	273,855	264,660	0,798	0,906	0,7
RFOA (#)	0,541	0,701	0,843	0,792	0,293	0,128	0,007
RTFOA (ms)	0,554	0,742	0,877	0,845	0,389	0,08	<0,0001

Analyses and results

- Diagrams with 15 classes, **P**
 - Statistically significant
 - Average cognitive effort with D are greater than the ones with U
 - Performance is greater with U than with D
 - Not significant
 - G with respect to U
 - S with respect to U

Analyses and results

- Diagrams with 15 classes, **C**



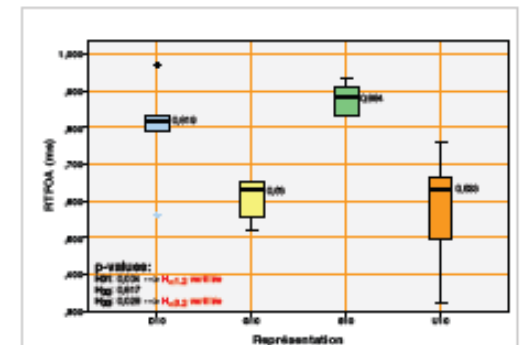
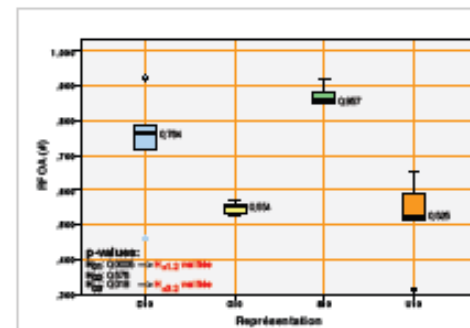
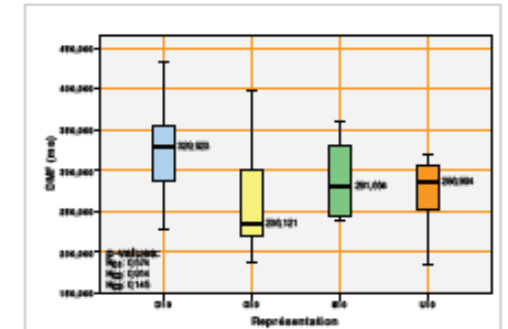
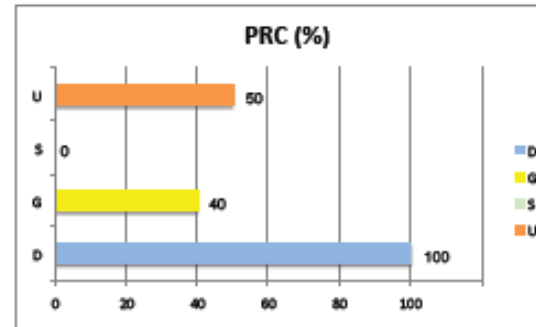
	P_D15	P_G15	P_S15	P_U15	p-value (H_{0_1})	p-value (H_{0_2})	p-value (H_{0_3})
PRC (%)	100	50	100	83,33	—	—	—
DMF (ms)	280,11	279,76	230,847	245,123	0,567	0,425	0,332
RFOA (#)	0,667	0,651	0,56	0,426	0,219	0,033	0,015
RTFOA (ms)	0,733	0,705	0,631	0,453	0,091	0,02	0,008

Analyses and results

- Diagram with 15 classes, **C**
 - Statistically significant
 - Average cognitive effort with D and G is less than the one with U
 - Performance is greater with D than U (but not with G)
 - Not significant
 - S with respect to U

Analyses and results

- Diagram with 15 classes, **R**



	P_D15	P_G15	P_S15	P_U15	p-value (H_{0_1})	p-value (H_{0_2})	p-value (H_{0_3})
PRC (%)	100	40	0	50	—	—	—
DMF (ms)	327,063	268,434	289,361	272,855	0,574	0,914	0,145
RFOA (#)	0,737	0,548	0,87	0,52	0,0005	0,576	0,018
RTFOA (ms)	0,798	0,602	0,879	0,584	0,004	0,817	0,028

Analyses and results

- Diagram with 15 classes, **R**
 - Statistically significant
 - Average cognitive effort is less with D and S than the one with U
 - Performance is greater with D than with U (but not with S)
 - Not significant
 - G with respect to U

Analyses and results

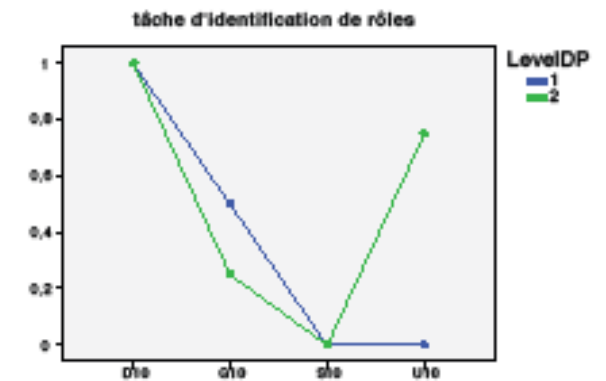
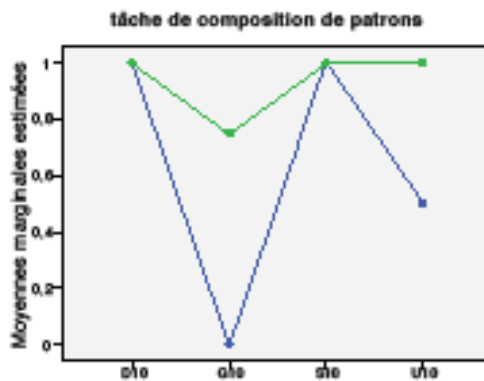
- Impact of the mitigating variables
 - Knowledge of JHotDraw not interesting, all subjects knew it!
 - Test ANOVA « 2-way »

	Rponses (C)	RFOA (C)	Rponses (P)	RFOA (P)	Rponses (R)	RFOA (R)
Niv_Connaissance_DP	0,028	0,31	0,828	0,21	0,458	0,955
Combin	0,131	0,955	0,989	0,93	0,158	0,064

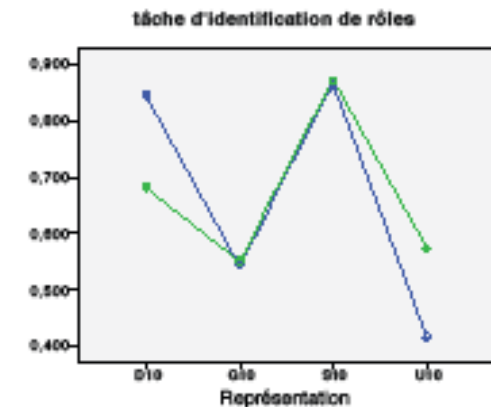
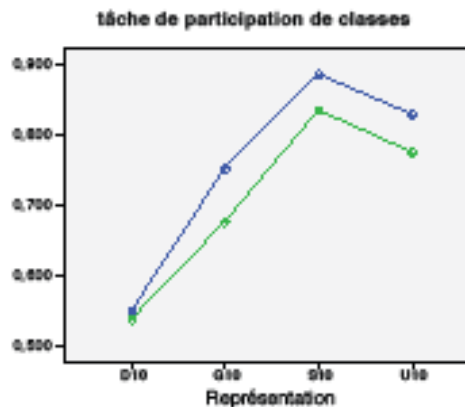
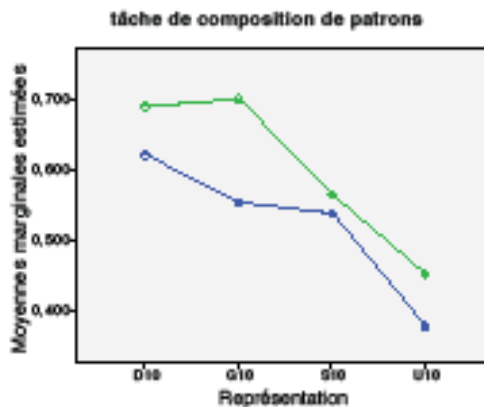
Analyses and results

– Test ANOVA « 2-way » (cont'd...)

Moyennes marginales estimées des réponses



Moyennes marginales estimées de RFOA





Analyses and results

- Test ANOVA « 2-way » (...end)
 - Significant difference in favour of G with respect to U for C when subjects where experts in design patterns

Analyses and results

■ Conclusions

– Task **P**

- H_{P0_1} : there is no difference in the subjects' average cognitive effort between representations U et S. However, even if PCR is slightly greater for U (PCR with U = 100%, PCR with S = 83,33%), S has similar cognitive impact in effort and time than U.
- H_{P0_2} : there is no difference in the subjects' average cognitive effort between representations U et G. The percentage PCR with U is greater by 50% to the one with G.
- $H_{P\alpha_3.1}$: the subjects' average cognitive effort between D is greater than the one with U. The percentage PCR with U is also greater by 50% to the one with D.

Analyses and results

■ Conclusions

– Task C

- H_{C0_1} : there is no difference in average cognitive effort with U and S. The percentage PCR is slightly greater with S than with U (PCR with U = 83,33%, PCR with S = 100%).
- $H_{C\alpha_2.2}$: the subjects' average cognitive effort with G is less than the one with U. However, the percentage PCR with U is greater by 50% to the one with G. A mitigating study shows that performance with G is greatly impacted by the subjects' knowledge of design patterns.
- $H_{C\alpha_3.2}$: the subjects' average cognitive effort with D is less than the one with U. Their percentage PCR with D is also slightly greater than the one with U.



Analyses and results

■ Conclusions

– Task **R**

- $H_{R\alpha_1.2}$: the subjects' average cognitive effort with S is less than the one with U. However, even though it is not significant, we found a greater effort to understand S. The percentage PCR with S is 0%, possibly because of the lack of information in the representation.
- H_{R0_2} : there is no difference between the subjects' average cognitive efforts with U and G. The percentages PCR with G and U are also very similar.
- $H_{R\alpha_3.2}$: the subjects' average cognitive effort with D is less than the one with U. The percentage PCR with D is greater by 50% to the one with U.



Threats to the Validity

■ Internal validity

Influence on independent variables

- Maturation
 - Learning effect
- Instrumentation
 - Measurement errors
- Diffusion of the treatments
 - Trust



Threats to the Validity

■ Construction validity

Generalisation

- Bias mono-method
 - Four independent variables
- Estimation of the hypotheses
 - Subjects were unaware of the hypotheses
- Fear
 - Explications et anonymousness
- Bias mono-operation
 - Only JHotDraw... future work!



Threats to the Validity

■ External validity

Generalisation

- Interaction between the selection
 - Subjects are representative
- Interaction in settings
 - The object and the diagrams are representative



Threats to the Validity

■ Conclusion validity

Influences on the conclusions

- Hypotheses of the statistical tests
 - Respect of their hypotheses
- Fiability of the measures
 - Measures from the literature
- Random errors in settings
 - Procedure, quiet environment
- Heterogeneity of the subjects
 - Mitigating variables



Conclusion

■ Participation

- Subjects did better with U than with D; no conclusion for G and S

■ Composition

- Subjects did better with D than with U; G seems better but with less correct answers; G is better with experts

■ Identification

- Subjects did better with D than with U



Future Work

- Replications, replications, replications
- Dealing with more threats
- Other design motifs
- Other representations
 - From the literature
 - From the results
 - Interactivity