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Cduvce

Although the recent success of convolutional neural network (CNN) advances state-of-the-art saliency prediction in static images, few work has addressed the problem of predicting attention in videos. On the other hand, we find that the attention of different subjects consistently focuses on a single face in each frame of videos involving multiple faces. Therefore, we propose in this paper a novel deep learning (DL) based method to predict salient face in multiple-face videos, which is capable of learning features and transition of salient faces across video frames. In particular, we first learn a CNN for each frame to locate salient face. Taking CNN features as input, we develop a multiple-stream long short-term memory (M-LSTM) network to predict the temporal transition of salient faces in video sequences. To evaluate our DL-based method, we build a new eye-tracking database of multiple-face videos. The experimental results show that our method outperforms the prior state-of-the-art methods in predicting visual attention on faces in multiple-face videos.

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vq o qfgn cvwgvkqp qp xkfgqu0 Jwc *et al.*]35_ rtqrugf vq ngctp okffng/ngxgn hgcvtgu. k0g0. ikuvu qh c uepgg. cu vjg ewg kp xkfgq ucnkgpe{ rtgfkevqp0 Twfq{ *et al.*]59_ rtqrugf vq rtgfkev ucnkgpe{ qh c ikxgp htcog ceeqtfkpi vq kvu jki j/ cpf nqy/ngxgn hgcvtgu. eqpfkvkqpqf qp vjg fgvgvgf ucnkgpe{ qh vjg rtgxkquw tghgtgpeg htcog0 Jqyngxg. vq qwt dguv mpqyn/ gfig. vjg gzkuvkpi xkfgq ucnkgpe{ rtgfkevqp ogvjquf tgn{ qp vjg jcpfctvgf hgcvtgu. fgurkvg EPP dgkpi crnkpf vq cw/ vqocvkecn{ ngctp hgcvtgu hqt kocig ucnkgpe{ rtgfkevqp kp vjg oquv tgegpv yqtmu qh]36.46.47.4:.54_0 Oqtg korqt/ vcpvn{. dqvj nqpi/ cpf ujqtv/ vgt o eqttgncvkqp qh ucnkgpv hcegu cetquu htcogu. yjkej ku etkvecn kp oqfgnkpi cvwgvkqp vtcp/ ukvqp cetquu htcogu hqt o wnvkrng/hceg xkfgqu *ugg Hkiwtg 3+. ku pqv vcmgp kpq ceeqwpv kp vjgug ogvjquf0

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Pwodgt qh xkfgqu *kk+	43	35	7	57	3:	:	322

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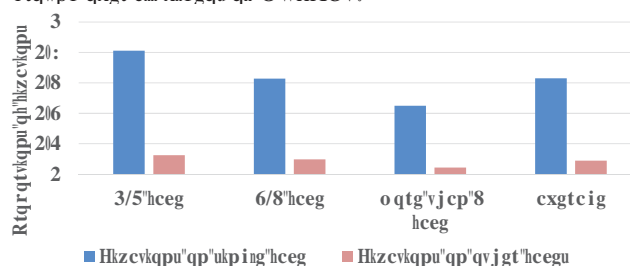
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Finding 1: In multiple-face videos, faces draw a significant amount of attention. At each video frame, attention of different subjects consistently focuses on one face among all faces.

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Finding 2: Humans probably fixate on the face that is close to the video center, among all faces at a video frame.

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 yjkej ku fkuewuugf kp Ugevkkp 5040 Ugevkkp 505 rtgugpvu O/
 NUVO vjcv ngctpu vq rtgfkev ucnkgpv hceg. d{ vcmkpi kpvq eqp/
 ukfgtcvkqp ucnkpe{/tgvvgf hgcvwtgu qh EPP cpf vjg vgo rq/
 tcn vtcupvkqp qh ucnkgpv hcegu cetquu xkfgq htcogu0 Kp vjg
 gpf. yg cfqrv c rquv/rtqeguukpi uvgr vq igpgtcvg ucnkpe{
 ocru qh o w n v k r n g / h c e g x k f g q u . f k u e w u u g f k p U g e v k k p 5 0 6 0

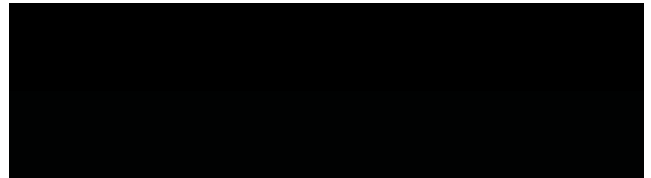
5030 Hceg Ecpfkfcvg Ipggtcvkqp

Dcug qp *Finding 1*. yg Łtuv gztcev hcegu cu qwt ecpfk/
 fcvg tgikqu hqt xkuwn cvgpkqp rtgfkevkkp kp c o w n v k r n g /
 h c e g x k f g q 0 V q v j k u g p f . y g n g x g t c i g v j g n c v g u v h c e g f g v g e /
 v k q p o g v j q f . v j g h w p p g n / u v t w e v w t g f e c u e c f g * H w U v + f g v g e v k q p
 o q f g n] 5 ; _ . v q g z t c e v e c p f k f c v g h c e g u h t q o c p k p r w v x k f g q 0
 Oqtgqxgt. kp qtfgt vq jcpfng ejcnmpikpi ecugu. uwej cu rct/
 vkn qeenwukqp cpf rqqt nki jv eqpfvkqp. yg gznqtg vgo rq/
 tcn kphqtocvkqp vq k o r t q x g h c e g f g v g e v k q p r g t h q t o c p e g k p
 o w n v k r n g / h c e g x k f g q u 0

Oqtg urgekŁecm{. yg Łtuv ovej vjg hcegu cetquu htcogu.
 d{ ugctejkpi vjg hceg ykvj pgctguv Gwengkfgcp fkucpeg0 Yg
 vjgp kfgpvkh{ vjg pgctguv hcegu qh vyq eqpugewkxg htcogu cu
 vjg ovejgf hceg qh c u c o g r g t u q p . r t q x k f g f v j g k t f k u v c p e g
 ku nguu vjcp c vjtgujqnf<

$$th_E = \times \sqrt{w^2 + h^2}, \quad *3+$$

yjgtg w cpf h ctg ykvj cpf jgkijv qh vjg fgvgevgf hceg0
 Qvjgtkyug. yg tgiectf vjgo cu pqp/ovejki hcegu. dngpi/
 kpi vq fkhgtgpv rgtuqu0 Kp *3+. ku c rctcogvt vq eqpvtn
 vjg ugpuvkxkv{ qh hceg ovejki. cpf kv ku ukorn{ ugv vq 207
 kp vjku rcrgt0 Qp qpj jcpf. c u o q q v j Ł n v g t k u n g x g t c i g f v q
 k o r t q x g r t g e k u q p t c v g . x k c g n o k p c v k p i u q o g h e n u g c n t o u
 qh ytqpin{ fgvgevgf hcegu0 Qp vjg qvjgt jcpf. yg crnŁ c
 nkpgct kpvgrqncvkqp vq gzyvpf hceg fgvgevkqu vq pgkijdqtkpi



Hkiwtg 80 Ctejkgevwtg qh qwt EPP hqt vjg vcum qh rtgfkevki ucnkgpv
 hceg0

htcogu ykvjkp c unkfkpi ykpfqy. uwej vjcv vjg okuukpi hcegu
 ecp dg tgeqxgtgf0 Kp vjku rcrgt. vjg ngpivj qh unkfkpi ykp/
 fqy ku gorrtkecnŁ ejqugp vq dg 39. vq cejkgxg uwhŁekgpvn{
 jki j tgecnŁ tcvg qp vjg hceg fgvgevkqp tguwnvu0

5040 EPP hqt Hgcvwtg Gzvtcevkqp

Yg pqy fgukip c EPP vq cwvqocvkecnŁ ngctp hgcvwtgu
 htqo vjg fgvgevgf hcegu. hqt vjg vcum qh rtgfkevki yjgvjgt
 vjg fgvgevgf hceg ku ucnkgpv0 Vjg fgvgevgf hceg tgikqu ctg
 tguk|gf vq dg 256 × 256 dghqtg dgkpi ugpv vq vjg EPP0 Qwt
 EPP ku dcugf qp vjg *GoogleNet*]5:_ . ykvj cp cffkvkqpcn
 dvej pqt ocnŁcvkqp nc{gt]38_ chvgt gcej eqpxqnwvkqp nc{gt
 vq cxqkf qxgtŁvki0 Yg cnuq wug vjg rtg/vtckpgf *GoogleNet*
 cpf vjgp Łpg/vwpg vjg pgvyqtm wukpi OWHXGV/KK0 Hkiwtg 8
 ujquy vjg ctejkgevwtg qh qwt EPP0 Chvgt vjg eqpxqnwvkqpcn
 hgcvwtg gzvtcevkqp kp *GoogleNet*. yg wug vyq hwnnŁ eqppgev/
 gf *HE+ nc{gtu. ykvj *softmax* cevkvkvkqp hwpevkqp. vq fgekf
 yjgvjgt vjg hceg ku ucnkgpv qt pqv0 Vjg Łtuv HE nc{gt jcu 34:
 wpkvu. yjqug qvrvvu ctg wugf cu vjg hgcvwtgu hqt rtgfkevki
 vjg ucnkgpv hceg0 Vjg ugeqpf HE nc{gt jcu 4 wpkvu. kpfkecvkpi
 vjg ucnkgpv qt pqp/ucnkgpv hceg0

Hqt vtckkpi EPP. yg cwvqocvkecnŁ ncdgn gcej fgvgevgf
 hceg vq dg ucnkgpv qt pqp/ucnkgpv. ceeqtfkpi vq vjg Łzcvkqu
 hcnkpi kpvq vjg hceg tgikqp0 Qwt *Finding 1* kpfkecvgu vjcv vjg
 ucnkgpv hceg kp gcej xkfgq htcog cxgtcignŁ ftcy oqtg vjcp
 60% Łzcvkqu qh c n n h c e g u 0 J g p e g . v j g h c e g u v j c v v c m g w r
 cdqgxg 60% Łzcvkqu ctg cppqvcvgf cu ucnkgpv hcegu. cpf qvjgt
 hcegu ctg uggp cu pqp/ucnkgpv qpqu0 Yg vjgp vtckp qwt EPP
 d{ vjg dcemrtqrcicvkqp *DR+ cniqtkvj o w u k p i O W H X G V / K K
 qh qwt g{g vtcemkpi fcvdcug cu vjg vtckkpi fcvd0 Ixgvp vjg
 vtckpgf EPP. 34:/fkogpukqp hgcvwtgu qh vjg Łtuv HE nc{gt
 ecp dg gztcevgt htqo gcej fgvgevgf hceg. yjkej ctg hgf kpvq
 qwt tgewtgpv pgvyqtm cu kprwv0

5050 O/NUVO hqt Ucnkgpv Hceg Rtgfkevkkp

Vjg EPP fgŁpgf cdqgxg ockpnŁ gztcev urcvkn kphqtoc/
 vkqp qh gcej hceg cv c ukping htcog0 Vq oqfgn vgo rqtcn f{/
 pcouku qh cwgpvkqp vtcupvkqp kp xkfgqu. yg pqy fgxgnqr c
 pqxgn O/NUVO vq rtgfkev ucnkgpv hceg kp vjg xkfgq ugwkpi0

Yg hqtowncvg vjg o wnvkrng/hceg ucnkgpe{ rtgfkevq cu c tgitguukqp rtqdnog. cpf dwknf cp O/NUVO pgvyqtm vq igpgtcvg vjg eqpvkpwqwu ucnkgpe{ ygki jvu qh o wnvkrng hcegu0 Vjku fkhgtgpkvcvgu qwt crrtqcej htqo vjg eqpxgpkqpcn N/NUVO]33_ hqt encuukLecvkqp0 Hqtocnn{. yg cko vq rtgfkev ucnkgpe{ ygki jvu qh gcej hceg fgLpgf d{ $\mathbf{w}_{n,t}$. yjkej ku vjg itqwpf vtwwj *IV+ cwgpkqp rtqrqtvkqp qh vjg \mathbf{n}/\mathbf{v} hceg vq cnn hcegu kp htcog t0 Hqt uwej rtgfkevq. O/NUVO pgvyqtm igpgtcvgu cp guvkocvgf ucnkgpe{ ygki jv $\hat{\mathbf{w}}_{n,t}$. yjkej ecp dg hwtvjgt tgitcvgf cu vjg qrvok|cvkqp hqt o wncvkqp<

$$\min_{s.t.} \sum_{t=1}^T \sum_{n=1}^N \|\hat{\mathbf{w}}_{n,t} - \mathbf{w}_{n,t}\|_2^2$$

$$\hat{\mathbf{w}}_{n,t} = \mathbf{w}_{n,t}, t = 1, 2, \dots, T, *4+$$

Qwt O/NUVO vcmgu vjg EPP hgcvtgu $\{\mathbf{f}_{n,t}\}_{n=1, t=1}^{N,T}$ cu kprwv. yjgtg $\mathbf{f}_{n,t}$ uvcpf hqt hgcvtg xgevqt qh vjg \mathbf{n}/\mathbf{v} hceg cv htcog t0 Yg cuuwog cp wrrgt nokv qh \mathbf{N} hcegu rgt xkfgq0 Yjgp hgyt hcegu * \mathbf{N} + ctg fgvgvgf kp c xkfgq htcog. vjg eqttgurqpfkpi kprwv vq O/NUVO ku |gtq xgevqt0 Pqvg vjcv qpeg vjg hceg qh c rgtuqp fkucrrgtu chvgt c hgy htcogu kp c xkfgq ugswwpeg. vjg eqttgurqpfkpi hgcvtg xgevqt $\mathbf{f}_{n,t}$ ku ugv vq |gtq xgevqt0 Qp vjg qvjgt jcpf. kh c pgy hceg crrgtu chvgt c hgy htcogu qh c xkfgq ugswwpeg hqt qpg o qtg rgtuqp. kvu gzvtcevgf kprwv hgcvtgu $\mathbf{f}_{n,t}$ tgrnceg vjg |gtq xgevqt0 Ikx/gp $\mathbf{f}_{n,t}$. c ukping NUVO ejwpm ku crnkgt vq qdvckp jkffgp xctkdng xgevqt $\mathbf{h}_{n,t}$. cu hqnnqyu.

$$\mathbf{h}_{n,t} = \text{LSTM}(\mathbf{f}_{n,t}, \mathbf{h}_{n,t-1}), *5+$$

yjgtg $\text{LSTM}(\cdot)$ tgrtgugpvu cp NUVO ejwpm0 Hqt vjg NUVO/ O ejwpm. yg wug vjg uvcpfctf NUVO yjkej kpenwfgu kprwv. hqtigv cpf qwwrvw icvgu0 Kv ku yqtvj ogpvkpkpi vjcv vjg NUVO/ O ejwpm ku ecrdng qh ngctkpi nqpilujqtv/vgt o fgrgpfge{ qh ucnkgpv hceg vtcupvkqp cu ygm cu qxgteqokpi vjg rtqdnog qh xcpkujkpi itcfkpgv0

Vjg jkffgp hgcvtg $\mathbf{h}_{n,t}$ ku vjgp rcuugf vjtqwi j c HE nc{gt hqnnqyg d{ TgevkLgf Nkpgct Wpkvu *TgNW+ cu hqnnqyu.

$$\mathbf{s}_{n,t} = \max(0, \mathbf{V} \cdot \mathbf{h}_{n,t}), *6+$$

yjgtg \mathbf{V} ku vjg rctcogvt ocvtkz hqt vjg HE nc{gt0 Vq ecr/vwtg vjg eqttgncvkqp dgvyggp hcegu kp qpg xkfgq htcog. yg dwknf c ugeqpf HE nc{gt vjcv vcmgu $\{\mathbf{s}_{n,t}\}_{n=1}^N$ qh fkhgtgpv hcegu cv vjg \mathbf{t}/\mathbf{v} htcog cu kprwv. cpf vjgp igpgtcvgu \mathbf{N} qww/rwvu0 Vjgug qwwrvw ctg vjgp rcuugf vjtqwi j c *softmax* nc{gt vq rtqfweg vjg Lpcn ucnkgpe{ ygki jv rtgfkevqpu<

$$\hat{\mathbf{w}}_{n,t} = \frac{\exp\{\mathbf{n} \cdot \sum_{n=1}^N (\mathbf{U}_{n,t} \cdot \mathbf{s}_{n,t} + \mathbf{b}_{n,t})\}}{\sum_{n=1}^N \exp\{\mathbf{n} \cdot \sum_{n=1}^N (\mathbf{U}_{n,t} \cdot \mathbf{s}_{n,t} + \mathbf{b}_{n,t})\}}, *7+$$

yjgtg $\mathbf{U}_{n,t}$ cpf $\mathbf{b}_{n,t}$ ctg rctcogvtu qh vjg HE nc{gt. yjknq \mathbf{n} ku rctcogvt qh *softmax* nc{gt0

Hkpcnn{. $\hat{\mathbf{w}}_{n,t}$ ecp dg qdvckpgf d{ qwt O/NUVO fgpqvgf cu $ML(\mathbf{P}, \mathbf{f}_{n,t})$. yjgtg \mathbf{P} ku vjg rctcogvt ugv qh O/NUVO vq dg ngctpgf0 Hqt \mathbf{P} . dg{qpf rctcogvt ujctkpi cetquu vkog kp qpg eqpxgpkqpcn NUVO . qwt o wnvkrng NUVOu kp qpg htcog cnuq ujctg rctcogvtu hqt fkhgtgpv hcegu0 Kv ku dgecwug vjg ucnkgpe{ ejcpikpi oqfg kp fkhgtgpv hcegu ku ukoknct0 Cu uwej. rctcogvtu htqo fkhgtgpv NUVOu ctg wrfcvgf cv vjg ucog vkog0 Vq ngctp cnn rctcogvtu \mathbf{P} . vjg nquu hwpevkqp qh qwt O/NUVO fgtxgf htqo *4+ ku

$$\text{Loss} = \sum_{t=1}^T \sum_{n=1}^N \|\text{ML}(\mathbf{P}, \mathbf{f}_{n,t}) - \mathbf{w}_{n,t}\|_2^2. *8+$$

Yjgp vtckpki qwt O/NUVO ykvj nquu hwpevkqp *8+. dcem rtqrcicvkqp vjtqwi j vkog *DRVV+ ku wvknk|gf vq ngctp rc/ tcovgtu \mathbf{P} ykvj cfcvrxg oqogpv guvkocvkqp *Cfco+ itc/ fkgpv fguegvp qrvok|cvkqp cniqtqv o]45_0 Chvgt vtckpki O/NUVO. $\hat{\mathbf{w}}_{n,t}$ ecp dg cejkxgf hqt rtgfkevki ucnkgpv hcegu0

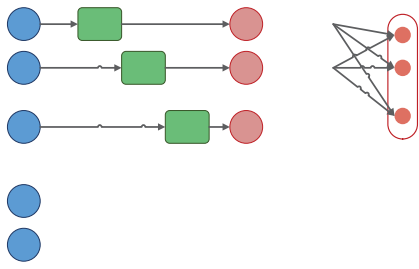
5060 Rquvrtqeguukpi

Chvgt qdvckpki ucnkgpe{ ygki jv qh gcej hceg htqo O/NUVO. rquvrtqeguukpi ku tgswwtgv vq igpgtcvg Lpcn ucnkgp/ e{ ocr0 Oqtg urgekLecnn{. yg Ltuv ocmg wug qh rtgfkevqf ucnkgpe{ ygki jv $\{\hat{\mathbf{w}}_{n,t}\}_{n=1}^N$ vq igpgtcvg eqpurkewkv{ ocr⁴ qh hceg ejcppgn. fgpqvgf cu \mathbf{M}_t^F 0 Kv ecp dg eqo rwvgf d{

$$\mathbf{M}_t^F = \sum_{n=1}^N \hat{\mathbf{w}}_{n,t} \cdot \mathbf{c}_{n,t} \cdot \mathbf{M}_t^{F^n}, *9+$$

yjgtg $\mathbf{M}_t^{F^n}$ fgpqvgu vjg eqpurkewkv{ qh vjg \mathbf{n}/\mathbf{v} hceg. cpf $\mathbf{c}_{n,t}$ ku vjg egpvt/dku ygki jv qh gcej hceg0 Kp qwt ogvjqf. $\mathbf{M}_t^{F^n}$ ku ecnewncvgf d{ vjg ncvgu yqtm]63_. yjkej oqfgn/ u vjg eqpurkewkv{ ocr qh c hceg ykvj vjg Icwuukcp okzvtg oqfgn *IOO+0 Kp cffkvkqp. *Finding 2* jcu tgxcngf vjcv xk/ uwen cwgpvkqp ku cnuq eqttgncvgf ykvj vjg egpvt/dku hgcvtg

⁴Pqvg vjcv ucnkgpe{ rtqfwegf d{ vjg ejcppgn qh ukping hgcvtg ku fgLpgf cu vjg eqpurkewkv{ ocr. kp qtfgt vq ocmg fkhgtgpeg htqo vjg ucnkgpe{ ocr yjkej ku igpgtcvgf d{ cnn ejcppgn0



Hkiwtg :⁰ Ucnkgpe{ ocru hqt fkhhtgtpv htcogu qh c xkfgq ugswwpeg ugngvvgf htqo OWHXGV/K0 Vjgug ocru ctg igpgtcvgf d{ IV jw/ ocp Łzcvkqpu. qwt ogvjqf. Zw *et al.* J63_. Ucnkeqp J36_. Lkcp *et al.* J43_. QDFN J34_. Twfq{ *et al.* J59_. RSHV]:_. Uwtrtkug J3:_ cpf IDXU J32_0

hqt ucnkgpe{ fgvgvkkp. yjkej ku cnuq eqo rctgf ykvj qwt FN/ dcugf ogvjqf0

Vjg oquv tgegpv yqtm qh J49_ jcu tgrqtvvgf vjcv pqtocn/ k|gf uecprcvj ucnkgpe{ *PUU+ cpf eqttgncvkqp eqghŁekgpv *E/ E+ rgthqto vjg dguv coqpi cmm ogvtkeu kp gxcnwcvkpi ucnkgp/ e{ rtgfkevkqp ceewtce{⁶ Vjgtgd{. yg eqo rctgf qwt ogvjqf ykvj qvjgt : ogvjqfu kp vgtou qh PUU cpf EE0 Vcdng 4 tg/ rqtvu vjg eqo rctkuqp tguwnvu qh ucnkgpe{ rtgfkevkqp. cxgt/ cigf qxgt cmm 87 vguv xkfgqu qh OWHXGV/K0 Yg ecp ugg htqo vjku vcdng vjcv qwt ogvjqf ku ovej dgvgv vjcp cmm qvjgt ogvj/ qfu kp rtgfkevkpi ucnkgpe{ qh owwvkrng/hceg xkfgqu0 UrgeŁ/ ecnn{. qwt ogvjqf jcu 20; : PUU cpf 2035 EE ko rtqxo ogpv qxgt J63_. vjg rgthqto cpeg qh yjkej tcpmu ugeqp0 Uvej cp ko rtqxo ogpv ku ockpn{ fwg vq vjg hqnnqykp tgcup< Ucnkgp/ e{ qh cmm hcegu ku ykvj gswcn ko rqtvcpeg kp J63_. yjkng vjg eqpukfgtcvkqp qh vg o rqtcn vtcupvkqp gpcdngu qwt ogvjqf vq ceewtvcgn{ rtgfkev ucnkgpv hceg cetquu htcogu0 Oqtgqxgt. kv ku yqtvj rqpvkpi qvv vjcv dqvj qwt ogvjqf cpf J63_ ctg uwrg/ tkqt vq J43_ yjkej ko rqugu wpgswcn ko rqtvcpeg qp fkhhtgtpv hcegu kp cp kocig0 Vjg ockp tgcup ku vjcv vjg wvknk|cvkqp qh qpn{ uvcvke hgcvwtgu kp J43_ oc{ rtgfkev ytapi ucnkgpv hceg kp c xkfgq0 Qp vjg qvjgt jcpf. nqpi ujqtv/vgt o vgo rqtcn vtcp/ ukvkqp qh qwt ogvjqf ku tgenn{ ghghevkg kp Łpfkpi vjg ucnkgpv

⁶ J49_ jcu cnuq ujqyp vjcv ctgc wpgft TQE *CWE+ ku vjg yqtuv ogvtke kp ogcuwtkpi ceewtce{ qh ucnkgpe{ rtgfkevkqp0

Hkiwtg ;⁰ Ucnkgpe{ ocru hqt ugxtcn htcogu ugngvvgf htqo fkhhtgtpv xkfgq ugswwpegu qh OWHXGV/K0 Vjgug ocru ctg igpgtcvgf d{ IV jw ocp Łzcvkqpu. qwt ogvjqf. Zw *et al.* J63_. Ucnkeqp J36_. Lkcp *et al.* J43_. QDFN J34_. Twfq{ *et al.* J59_. RSHV]:_. Uwtrtkug J3:_ cpf IDXU J32_0

hceg kp owwvkrng/hceg xkfgqu0

Pgzv. yg oqxg vq vjg eqo rctkuqp qh uwdlgevkg tguwnvu0 Yg ujyq kp Hkiwtg : vjg ucnkgpe{ ocru qh ugxtcn htcogu kp c xkfgq. igpgtcvgf d{ qwt cpf qvjgt : ogvjqfu0 Htqo vjku Łiwtg. qpq oc{ qdugtvg vjcv qwt ogvjqf ku ecrdng qh Łpfkpi vjg ucnkgpv hceg0 Cu c tguwnv. vjg ucnkgpe{ ocru qh qwt ogvjqf ctg oqtg ceewtvg vjcp vjqg qh qvjgt ogvjqfu0 Hqt gzc o rng. yg ecp ugg htqo Hkiwtg : vjcv vjg ucnkgpv hceg ku ejcpigf htqo vjg iktu vq vjg ocp cpf vjgp dcem vq vjg iktu. yjkej ku gzvtoggn{ eqpukvvgv ykvj qwt rtgfkevkqp0 Qp vjg eqpvtct{. J63_ Łpfu cmm vjtg hcegu cu ucnkgpv qpqu. cpf J43_ okuugu vjg ucnkgpv hceg qh vjg urgcnkpi ocp0 Kp cffkvkqp. Hkiwtg ; rtqxfkgu vjg ucnkgpe{ ocru qh vjg htcogu ugngvvgf htqo 7 xkfgqu0 Cickp. vjku Łiwtg xgtŁgu vjcv qwt ogvjqf ku cdng vq rtgekugn{ nqecvg ucnkgpv hceg d{ eqpukfgtkpi vgo rqtcn ucnkgpe{ vtcupvkqp kp O/NUVO0

6050 Rgthqt o cpeg cpcn{uku qh ucnkgpe{ rtgfkevkqp

Ukpeg qwt O/NUVO rtgugpvvgf kp Ugevkkp 505 ckou cv rtg/ fkevki ucnkgpe{ ygki jvu qh hcegu cetquu xkfgq htcogu. kv ku yqtvj gxcnwcvkpi vjg rtgfkevkqp gttat qh O/NUVO0 Vq vjku gpv. Hkiwtg 32 rnquv ucnkgpe{ ygki jvu qh hcegu d{ EPP. O/NUVO cpf IV. hqt vjg xkfgq ugswwpeg qh Hkiwtg :⁰ Kp vjku Łiwtg. vjg ewtxgu qh EPP tghgt vq vjg qwwrvv qh EPP *gk/ vjgt 2 qt 3+. cpf vjg ewtxgu qh O/NUVO ctg qdvckpgf wrqp

	Vcdng 40	Ceewtce{	qh ucnkqpe{	rtgfkewkqp d{	qwt cpf qvjgt :	ogvjqfu. cxgtcigf	qxgt cnn	vguv xkfqgu qh	OWHXGV/K0	
	Qwt	IV	Zw <i>et al.</i> j63_	Ucnkqpp j36_	Lkcpi <i>et al.</i> j43_	IDXU j32_	Twfq{ <i>et al.</i> j59_	RSHV j:_	Uwtrtkug j3:_	QDFN j34_
PUU	6034	6043	5036	40;8	20;9	3045	3064	20; :	20; :	3084
EE	2096	2099	2083	2074	204;	2055	2058	2044	2043	2052

Hkiwtg 320 Ucnkgp{ ygkijvu qh hegu cnqpi ykvj rtqeguuf htc ogu
hqt vjg xkfeg kp Hkiwtg 32. rtgfkvegf d{ qwt EPP *itggp nkgp+. O/
NUVO *dnwg nkgp+ cpf IV *tfg nkgp+0 Pqvg vjcv vjg IV kp vjku ewtxg
ku rnnwgf ykvj rtqrqtvkp qh jwocp Łzcvkqup kp gcej hecg vq vjqug
kp cnq hegu0 kp vjku Łkwg. vjg o gcp uswtcgt gttqt *OUG+ dgvyggp
O/NUVO cpf IV cxgtcigf qxgt 5 hegu ku 2022:30

*c+ PUU *d+ EE

Hkiwtg 330 Ucnkgpe{ rtgfkevqp rgthqt o cpeg xgtuwu fkhhtgp/
v egpvgt/dkcu rctc ogvgt qh *: +0

Tghgtgpegu

- [3]_ C0 Dqtlk cpf N0 Kvvk0 Uvcvg/qh/vjg/ctv kp xkuwcn cvgvpkqp oqfgnkp0 *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 57*3+3:76429. Lcp0 42350
- [4]_ P0 Dtweg cpf L0 Vuquvu0 Ucnkge{ dcugf qp kphqto cvkqp o czk0k/c/vkqp0 Kp *Advances in neural information processing systems (NIPS)*. 42270
- [5]_ P0 L0 Dwmq cpf L0 T0 Oqxgmcp0 Qrvkocn uecpkp0 hqt hcugt qdlge/v fgvgvkqp0 Kp *Computer Vision and Pattern Recognition (CVPR)*. rcigu 49736497: . 422;0
- [6]_ O0 Egh. L0 Jctgn. Y0 Gkjp0wugt. cpf E0 Mqej0 Rtgfkvpki jwocp iclg wukpi nqy/hgxgn ucnkge{ eqodkpgf ykvj hceg fgvgvkqp0 Kp *Advances in neural information processing systems (NIPS)*. 422:0
- [7]_ N0 Fwcp. E0 Yw. L0 Okcq. N0 Skpi. cpf [0 Hw0 Xkuwcn ucnkge{ fg/vgvpkqp d{ urcvkcm{ ykijvgf fkuukonctkv{0 Kp *Computer Vision and Pattern Recognition (CVPR)*. rcigu 69566:2. 42330
- [8]_ [0 Hcpi. Y0 Nkp. \0 Ejgp. E0/O0 Vuck. cpf E0/Y0 Nkp0 Xkfgq ucnkge{ fgvgvkqp kp vjg eqortguugf fqockp0 Kp *ACM international conference on Multimedia (ACM MM)*. rcigu 8;96922. 42340
- [9]_ O0 Itcpv. D0 Uvgrjgp. cpf [0 [g0 Exz< Ocmcd uqhvyctg hqt fkuwk/rnkpgf eqpxgz rtqitco okpi0 *cvxr.com*. 422:0
- [1]_ E0 Iwq cpf N0 \jcp0 Cpqxgn o wmkgtguqwkqp urcvkvgo rqtcn ucnkge/ e{ fgvgvkqp oqfgn cpf kvu crnrckvkapu kp kocig cpf xkfgq eqortgu/ uqkp0 *IEEE Transactions on Image Processing*. 3;*3+3:763; . Lcp0 42320
- []_ J0 Jcfk{cfgj. O0 L0 Gptkswg{. cpf K0 X0 Delk0 G{g/vtcmkpi fcvcdug hqt c ugq qh uvcpfctf xkfgq ugswgpegu0 *IEEE Transactions on Image Processing*. 43*4+; :6;25. 42340
- [32]_ L0 Jctgn. E0 Mqej. cpf R0 Rgtqpc0 Iterj/dcugf xkuwcn ucnkge{0 Kp *Advances in neural information processing systems (NIPS)*. rcigu 7676774. 42280
- [33]_ U0 Jqejtkvgt cpf L0 Uejoj kfwjdg0 Nqpi ujqtv/vgt0 ogoqt{0 *Neural computation*. *;+3957639:2. 3; :90
- [34]_ U0 Jqugkjp Mjcvqppcdcfk. P0 Xcuqpegnqu. K0 X0 Delke. cpf [0 Ujcp0 Jqy ocpf dkuu fggu kv veng hqt c uvko wnwu vq dg ucnkgepA Kp *Computer Vision and Pattern Recognition (CVPR)*. rcigu 772367732. 42370
- [35]_ [0 Jwc. \0 \jcp. J0 Vkc. Z0 Iwq. cpf C0 Eck0 Crtqcdnkukve ucnkge/ e{ oqfgn ykvj ogoqt{/iwkfgf vqr/fqyp ewgu hqt htgg/xkgykpi0 Kp *International Conference on Multimedia and Expo (ICME)*. rcigu 368. 42350
- [36]_ Z0 Jwcp0. E0 Ujgp. Z0 Dqkz. cpf S0 \jcp0 Ucnkgep< Tgfwekpi vjg ug/ ocpke icr kp ucnkge{ rtgfekvp d{ cfcrvki fggr pgwtcn pgvyqtmu0 Kp *International Conference on Computer Vision (ICCV)*. rcigu 4846 492. 42370
- [37]_ T0 N0 Kocp cpf Y0/L0 Eqpxgt0 C flutkdwkqp/htgg crrtqcej vq kp/ fwelkpi tcm eqtgnvkv coqpi kprwv xctkdngu0 *Communications in Statistics-Simulation and Computation*. 33*5+5336556. 3; :40
- [38]_ U0 Kqhhg cpf E0 Ujgigf{0 Dvej pqto cnk{cvkqp< Ceengtcvki fggr pgvyqtm vtckpki d{ tgfwekpi kpvgtpcn eqxctkvj ujkh0 *arXiv preprint arXiv:1502.03167*. 42370
- [39]_ N0 Kvvk0 Cwvqocvke hqxgcvkqp hqt xkfgq eqortguukqp wukpi c pgwtq/dkqaikecn oqfgn qh xkuwcn cvgvpkqp0 *IEEE Transactions on Image Processing*. 35*32+3526 6 353: . Fge 42260
- [3]_ N0 Kvvk cpf R0 Dcnfk0 Dc{gukcp uwtrtkug cwtcevu jwocp cvgvpkqp0 *Vision research*. 6;*32+34;763528. Lwp0 422;0
- [3]_ N0 Kvvk. P0 Fjxcng. cpf H0 Rkijkp0 Tgcnkukve cxcvct g{g cpf jgcf cp/ kocvkv wukpi c pgwtqdkqaikecn oqfgn qh xkuwcn cvgvpkqp0 *Optical Science and Technology*. 86*8669: . Lcp0 42260
- [42]_ N0 Kvk. E0 Mqej. cpf G0 Plgdwt0 C oqfgn qh ucnkge{/dcugf xkuw/ cn cvgvpkqp hqt terkf ueggp cpcn{uku0 *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 42*33+34766347: . Pqx0 3; :;0
- [43]_ O0 Lkcp0. L0 Zw. cpf S0 \jcp0 Ucnkge{ kp etqy f0 Kp *European Conference on Computer Vision (ECCV)*. rcigu 396540 Urtkpiqt. 42360
- [44]_ V0 Lwff. M0 Gjkipgt. H0 Fwtcpf. cpf C0 Vqttend0 Ngctpki vq rtgfkev yjgtg jwocpu nqgm0 Kp *Proc. ICCV*. rcigu 432864335. 422;0
- [45]_ F0 Mkipoc cpf L0 Dc0 Cfcoc< C ogvjqf hqt uvqejcvke qrvk0k{cvkqp0 *arXiv preprint arXiv:1412.6980*. 42360
- [46]_ U0 U0 Mtwvjxgvpk. M0 C{wuj. cpf T0 X0 Dcdw0 FggrLz< C hwnn{ eqp/ xqnvkqpcn pgwtcn pgvyqtm hqt rtgfekvpki jwocp g{g Lzcvkqp0 *arXiv preprint arXiv:1510.02927*. 42370
- [47]_ O0 Mw0 ogtgt. V0 U0 Ycmku. cpf O0 Dgvji0 Fggriclg k< Tgcfkpi Lzcvkqp0 hqo fggr hgcvwtgu vtckpgf qp qdlgev tgeqiplkvkqp0 *arXiv*. 3832023785. 42380
- [48]_ L0 Nk. O0 F0 Ngxkpg. Z0 Cp. Z0 Zw. cpf J0 Jg0 Xkuwcn ucnkge{ dcugf qp uecng/urceg cpcn{uku kp vjg htgswgpe{ fqockp0 *Pattern Analysis and Machine Intelligence, IEEE Transactions on*. 42350
- [49]_ L0 Nk. E0 Zkc. [0 Uqpi. U0 Hcpi. cpf Z0 Ejgp0 C fcvc/ftlxgp ogvte hqt eqortgjpukxg gxcnwcvkqp qh ucnkge{ oqfgnu0 Kp *International Conference on Computer Vision (ICCV)*. 42370
- [4]_ P0 Nkw. L0 Jcp. F0 \jcp0. U0 Ygp. cpf V0 Nkw0 Rtgfkvpki g{g Lzcvkqp wukpi eqpxqnvkqpcn pgwtcn pgvyqtmu0 Kp *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. rcigu 5846592. 42370
- [4]_ G0 Ocvk0 Uceefk uwrtrtguukp< c tgxkgy cpf cp cpcn{uku0 *Psychological bulletin*. :3*34+; :;6;39. Fge0 3;960
- [52]_ R0 M0 Okvcn. V0 L0 Uokvj. T0 N0 Jkm. cpf L0 O0 Jgpfgtuqp0 Enwuvgt/ kpi qh iclg fwtkpi f{pcoke ueggp xkgykpi ku rtgfkev d{ oqvkqp0 *Cognitive Computation*. 5*3+7646. Oct0 42330
- [53]_ V0 X0 Pw{gp. O0 Zw. I0 Icq. O0 Mcpncpjcnnk. S0 Vkc. cpf U0 [cp0 Uvcvke ucnkge{ xu0 f{pcoke ucnkge{< c eqo rctevkxg uwvf{0 Kp *ACM international conference on Multimedia (ACM MM)*. rcigu :;96; ;8. 42350
- [54]_ L0 Rcp. M0 OeIwkpogu. G0 Uc{tan. P0 Q0 Eqppqt. cpf Z0 Iktq/k Pk/ gvq0 Ujcmqy cpf fggr eqpxqnvkqpcn pgvyqtmu hqt ucnkge{ rtgfek/ vkqp0 *arXiv preprint arXiv:1603.00845*. 42380
- [55]_ F0 Rcp0. C0 Mkwtc. V0 Vcmgewjk. L0 [ocvq. cpf M0 Mcujkp0 C u/ vqejcvke oqfgn qh ugnvkvxg xkuwcn cvgvpkqp ykvj c f{pcoke dc{gukcp pgvyqtmu0 Kp *International Conference on Multimedia and Expo (ICME)*. rcigu 329563298. 422:0
- [56]_ T0 L0 Rvgtu cpf N0 Kvvk0 Dg{qpf dqwqo/wr< Kpeqtrqtcvki vcm/ fgrppfgrv kplwgegu kvq c eqo rwcvkqpcn oqfgn qh urcvkcn cvgvp/ vkqp0 Kp *Computer Vision and Pattern Recognition (CVPR)*. rcigu 36: . 42290
- [57]_ W0 Telcujgmct. K0 Xcp Fgt Nkpf. C0 E0 Dqxm. cpf N0 M0 Eqto cem0 Ichhg< C iclg/cvgvpkxg Lzcvkqp Lpfkpi gpikp0 *Image Processing, IEEE Transactions on*. 422:0
- [58]_ X0 Teocpcvjcp. L0 Jwcp0. U0 Cdw/Gn/Jckc. C0 Iqtdcp. M0 Owt/ rj{. cpf N0 Hgk/Hgk0 Fgvgvkpi gxpvu cpf mg{ cevqtu kp o wnk/rgtuqp xkfgqu0 *Computer Vision and Pattern Recognition (CVPR)*. 42380
- [59]_ F0 Twfqf. F0 D0 Iqnfocp. G0 Ugejvop. cpf N0 \gnpkm/Ocpqt0 Ngctpki xkfgq ucnkge{ hqo jwocp iclg wukpi ecpfkfcvg ugnvkvkqp0 Kp *Computer Vision and Pattern Recognition (CVPR)*. rcigu 33696 3376. 42350
- [5]_ E0 Ujgigf{. Y0 Nkw. [0 Lk. R0 Ugtocpgv. U0 Tggf. F0 Cpiwnqx. F0 Gt/ jcp. X0 Xcpjqwemg. cpf C0 Tcdkpxkcej0 Iqkpi fggrgt ykvj eqpxqnv/ vkp0 Kp *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. rcigu 36; . 42370
- [5]_ U0 Yw. O0 Mcp. \0 Jg. U0 Ujcp. cpf Z0 Ejgp0 Hwppgn/uvtwewtgef ecu/ eefg hqt o wnk/xkgy hceg fgvgvkqp ykvj cnkipogpv/cyctpggu0 *Neurocomputing*. 42380
- [62]_ O0 Zw. N0 Lkcp0. \0 [g. cpf \0 Ycp0 Dqwqo/wr ucnkge{ fgvgvkqp ykvj urctug tgrtgugpvkvp qh ngctpv vgzwtg cvqou0 *Pattern Recognition*. 42380
- [63]_ O0 Zw. [0 Tgp. cpf \0 Ycp0 Ngctpki vq rtgfkev ucnkge{ qp hceg kocigu0 Kp *International Conference on Computer Vision (ICCV)*. 42370
- [64]_ L0 \jcp0 cpf U0 Uenctqhh0 Ucnkge{ fgvgvkqp< C dqngcp ocr cr/ rtqcej0 Kp *International Conference on Computer Vision (ICCV)*. rcigu 3756382. 42350
- [65]_ S0 \jcp cpf E0 Mqej0 Ngctpki c ucnkge{ ocr wukpi Lzcvgf nqec/ vkpu kp pcwtcn ueggpu0 *Journal of vision*. 42330